Master Thesis

Energy Smart innovation in the built environment - 120 hp

Smart Readiness Indicator Survey on Campus Varberg, Sweden

A study on potential energy savings and sustainable solutions

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Abstract

The aim of this thesis is to investigate how to lower the energy use in Campus Varberg. For this purpose, the thesis utilizes a case study methodology and the European commission's Smart Readiness Indicator (SRI) as a tool to see what actions that could and should be taken in Campus Varberg to increase the score, resulting in a more energy efficient Campus. Results are indicating that sensors for occupant and daylight detection, and demand side management (DSM) of the heating, ventilation and air conditioning system (HVAC), and manual override of DSM are critical to increase energy efficiency and comfort in the building. A solar panel installation is recommended, and the expected gains are calculated. Unfortunately, the addition of an energy storage is not reasonable to install, because the expected production is lower than the current energy consumption, which limits Campus Varberg from proceeding further as a smart building. Overall, the SRI survey has proven to be a useful tool for identifying energy-saving opportunities and guiding the implementation of sustainable solutions in Campus Varberg, Sweden.

Keywords: Smart Readiness Indicator (SRI), system installations, energy efficiency & smart buildings.

Preface

The authors of this master thesis would like to send a warm thank you to several people who have helped us in the creation of this work.

First on the list is our supervisor for providing general guidance and critical but very helpful input on the content, Mohsen Soleimani-Mohseni

Secondly, we would like to direct a thank you to Heidi Norrström for helping us structure the report in an efficient manner, and Fredric Ottermo for supporting us with technical input.

Lastly, we would like to thank the companies System Installation AB & Varberg Fastigheter AB for assisting us with information gathering. Without the companies' commitment and great interest in the development of the subject and the property, it would not have been possible to carry out the study. From System Installation AB, we would like to lift David Svalander as a great contact person, who assisted us with the complete system installation and walkthrough of the SRI sheet.

The thesis would not have been possible without these individuals, so ones again. A huge thank you to all of the people and companies mentioned above.

Halmstad, May 2023

Tobias Mohlin & William Berg

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1. Introduction

1.1 Background

Buildings and properties are one of the biggest energy thieves in society. In the year 2022, the operational energy demand in non residential buildings accounted for 9 % of the total final energy consumption. Likewise, the operational energy related co_2 emissions, also for non residential buildings, accounted for 11 % of the global amount (United Nations Environment Programme., 2022). These values excluded the energy demand and emission releases which occur during material manufacturing and construction, so one may assume that the actual values are slightly higher. This makes measures aimed at lowering the operational energy demands in non residential buildings an important field to study, in order to decrease the energy demands and connected carbon emissions which arises due to the utilization of existing buildings. We are making progress to handle these issues, but unfortunately, society is not advancing quickly enough. The United Nations has therefore called for a decade of action which began in 2020 and spans to 2030, with the goal of rapidly progressing towards the 17 different sustainable development goals, or SDGs for short (United Nations, n.d.). Out of the 17 goals, the ones seen in figure 1, 2 and 3 are most relevant in regards to this literature.

- **Goal nr 7 - Affordable and clean energy**

Figure 1. Goal 7, Sustainable Development Goals, (United Nations, 2021a).

SDG goal 7 is "Affordable and Clean Energy", which is associated with ensuring that the possibility exists for reliable, sustainable but also affordable energy is available to all users. This is relevant to this thesis because clean and affordable energy is achieved by reducing greenhouse gas emissions and energy consumption on Campus Varberg, and in this way the campus property is energy optimized.

- **Goal nr 11 - Sustainable Cities and Communities**

Figure 2. Goal 11, Sustainable Development Goals, (United Nations, 2021b).

SDG goal 11 is "Sustainable Cities and Communities", which means creating sustainable urban development where no one is left out and you build to make cities safer for the future.

Energy optimization for the property Campus Varberg is relevant to this thesis with regard to the fact that sustainable cities and communities can contribute by reducing the environmental impact of the property as well as improving the entire energy efficiency.

- **Goal nr 12 - Responsible Production and Consumption**

Figure 3. Goal 12, Sustainable Development Goals, (United Nations, 2021c).

The last SDG goal relevant to this thesis is goal number 12 which is "Responsible Consumption and Production", it aims to guarantee sustainable consumption and production patterns. This goal is relevant for this thesis because energy optimization of a campus property can promote responsible consumption and production by reducing energy waste and minimizing Campus Varberg's carbon footprint.

These are the most relevant to this thesis because energy optimization of a campus property can directly contribute to achieving these goals. Some essential determining factors for achieving these SDGs goals that are mentioned are promoting sustainable consumption and production patterns, reducing energy waste and reducing the emissions that consist of greenhouse gasses.

In the landscape of sustainable urban development the concept of Smart Readiness Indicators (SRIs) has emerged as a pivotal tool to help assess technological and energy related functions in buildings. SRI originates from the European Commission’s thanks to its commitment to advance the energy efficiency and digital integration of buildings. The topic has seen a large body of research and has thus been explored thoroughly since its inception.

1.2 Campus Varberg & Varberg Fastigheter AB

One such building that is in dire need of refurbishment is a university campus located in Varberg, Sweden. The occupants have complained about comfort issues such as the facility being too hot during late spring or summer times, and too cold during the winter months. The uncomfort felt during spring and summer is primarily related to irradiation in combination with large window panes on the building facades, according to Magnus Aronsson who works for the facility owners, Varberg Fastigheter AB. Although Varberg Fastigheter AB shares the concerns from their occupants regarding comfort, there are additional issues which they wish to address (Aronsson, 2023). Due to rising energy prices in Sweden, they have asked for ways to decrease their energy usage. They have prior to this thesis worked with optimizing the operational hours of their ventilation and lighting system. In addition, they have also begun cooperating with a company called System Installation, or SI for short. SI installed a building control system in the facility year 2018, in order to measure and adjust the HVAC systems operations. However, the building's HVAC system is quite inefficient in regard to its flexibility, and can therefore not be fully utilized by the control system. In the nondomestic sector, HVAC systems account for roughly 50 % of the total energy consumption (Korolija I., 2011). It would hence be interesting to study how one can effectively integrate older buildings with smart building control systems.

1.3 Aim

The aim of this Master's thesis will be to utilize the European commission's Smart Readiness Indicator as a tool to see what actions can and should be taken on Campus Varberg, to increase the score. The thesis will also investigate if the actions which have the highest impact on the final SRI scores, can be correlated to the actions which provide the highest energy savings.

2. Theory

When discussing energy savings in buildings, the greatest action to take, generally speaking, is to lower the energy needed to sustain the building operation (Felius, L. C. et al.,2020). New buildings tend to have sufficient insulation and energy efficient windows, making actions aimed at lowering the energy demand difficult to achieve. However, older buildings are strongly incentivised to make refurbishments aimed at lowering their energy demands. According to Al Dakheel et al. (2020), up to 90 % of the current European buildings are estimated to be standing until 2050, which gives a strong incentive to upgrade the existing retrofitting strategies towards Smart Retrofitting. The aim of such action is to first of all reach the nearly Zero Energy Building (nZEB) target. But also to provide buildings with the necessary tools needed to be reactive towards external dynamic conditions, such as weather conditions and flexibility in the electrical grid. To clarify, if a building produces an even amount of energy for its total consumption, or produces a net gain, it is commonly referred to as a Nearly Zero Energy Building (nZEB). According to Deng et al. (2014), there are primarily three different types of energy sources used by these types of buildings, namely, renewable energy power, on-site generation as well as backup and bulk generation. To get everything connected, smart reading meters and up-to-date communication between the system's hardware will also need to be connected to local and national systems. By transitioning our buildings towards the nZEB standards, it is inevitable that more renewable energy sources (RES) will be included in the electrical grid and electrical distribution. However, due to the uncertainty of produced electricity that is often correlated with RES such as solar cells and wind turbines, in combination with a growing electricity consumption, there is a need for a certain control mechanism, referred to as a smart grid (Arteconi et al. 2019). Arguably, the concept of a smart grid is nothing more than a regular grid, with added flexibility and intelligent decision making capabilities. Groppi et al. (2021) defined grid flexibility as “the ability of the system to rapidly respond to unpredicted variations”. To sum up, with the goal of achieving nZEb building and increased flexibility, we should aim to integrate a smart grid system with innovative and preferably renewable technologies, with regard to buildings’ energy usage (Deng et al., 2014 & Arteconi et al., 2019).

By taking the concept of nZEB further, we got the concept of so-called smart buildings. A smart building has according to Al Dakheel et al. (2020) four different features.

1. The building targets the nearly zero energy building standard.
2. The building can respond to external factors and conditions such as the grid and climate *(flexibility)*.
3. The building responds to the users need, and lastly
4. The building uses a building energy management system to monitor, control and supervise building operations.

It is clear that flexibility plays an important role both as an aim but also as a necessity in order to classify buildings as smart buildings. However, older buildings may find it difficult to implement flexible energy management systems because their HVAC systems are, generally speaking, not advanced enough to utilize them properly. To tackle this issue, the European

Commission has introduced what is called the Smart Readiness Indicator (SRI). It is a tool that aims to measure the smart readiness of buildings, and their ability to optimize their energy usage while being reactive to the external dynamic conditions, all while taking the occupants' needs and comfort into consideration (European Commission, 2021).

2.1 The history and current state of knowledge

In the early 2010s, the Smart Readiness Indicator began to take shape and was part of the European Union's efforts to promote energy efficiency and sustainability in the construction sector. The goal was to develop and create a concept, or tool, with the ability to assess how ready a building is for a “smart” conversion, and which smart features were already available to help the building become more energy efficient. The Directive of the European Parliament and the Council (2010/31/EU).

Until September 2021, there had been extensive discussions and consultations with various stakeholders, including the construction and real estate sector, research institutes and political aspects, to define and design the methodology for the Smart Readiness Indicator. In addition, several pilot projects and tests had been carried out to evaluate the practical application of SRI.

One such example is the study done by Horák O & Kabele K (2019), who performed a case study where they tried to assess four buildings in the Czech Republic, with various levels of smart services. In the end, they concluded that it was practically impossible to conduct the study on a building which had two or more heat sources. They also concluded that certain impact scores, such as well-being, were insufficient, simply because there is a much too small number of services on which the impact scores were based. As a last note, they also mentioned how difficult it was for buildings to reach a 100 % score, simply because such buildings would require incredibly sophisticated intelligent systems, which would most likely prove to not be very user friendly. However, this also means that their assessed buildings had a lot of potential to improve on their parameters.

Janhunen, et al. (2019) aimed to provide the first insights of how efficient tool SRI was, when it was applied to cold climates. In their work, they applied the SRI methodological framework, as well as the streamlined version of the smart ready service catalog from the final report of the first SRI technical support study, onto three various buildings located in the Helsinki metropolitan region in Finland. The buildings were one modern educational building, a “regular” educational building, and finally a traditional office building. They thereafter concluded that the base design of SRI was not exactly feasible for cold climate countries. There needed to be changes in the framework, or the SRI tool would not be able to act as the equally applicable EU-wide energy efficiency activity tool that it set out to be. They suggested that in order to improve on the applicability of SRI, the service catalog could be applied as a baseline and help develop a specific framework designed towards cold climate countries. They also suggested removing the subjective decisions for certain sections during the triage process, such as “relevant building services”.

Vigna. I et al. (2020) explained in their study how the SRI progressed with the help of primarily two technical studies. The first was conducted by a consortium which included

VITO, Waide Strategic Efficiency, OFFIS and Ecofys. They proposed the framework and the inclusion of smart services. Other subsequent studies offered insights of the potential and limitations of SRI. For example, some studied the applicability of SRI on diverse building types, such as earlier mentioned Horák O & Kabele K (2019), others proposed algorithmic solutions to help streamline the assessment and quantitative alternatives. With concerns rising about the effectiveness of SRI, seeing how some of its worse qualities were being exposed as research on the methodology was taking place.

Vigna. I et al. (2020) thereafter tried to evaluate the SRI, and discuss the practicality of the tool based on their obtained results. They applied the SRI methodological framework on a nZEB office building in Bolzano, Italy. One of their main concerns was the importance of data collection, which is significantly affected by the available source of information, as well as how it directly impacts the functionality levels of the services which are being graded in SRI. To solve this issue, they suggested national guidelines including a source hierarchy for data collection, as well as a list of technologies with their relative functionality levels listed, for a smooth and efficient implementation.

Touching on the subject of nZEB once again, how does nZEB and SRI correlate to one another? In a study done by Paoletti G. et al (2017), they aimed to identify what technologies were adopted across Europe when constructing and renovating buildings towards nZEB. They narrowed their study down by focusing on how climate conditions influenced the choices of applied technologies. The general outcome was that climate conditions were not the main parameter that affected these choices, however, the availability of natural resources such as irradiation did affect the use of renewable technologies. They observed a smaller share of PVs in cold climates, and likewise an increased share in the warmer climates. The important part of their study was primarily the fact that "...the identification of the most used technology solutions in relation to the climate condition should be used…in order to identify the building market needs and address the efforts".

SRI is essentially a tool that helps with the identification of the most used technologies, and could therefore be said to have an important role towards a more efficient conversion towards nZEB buildings. Thankfully, on December 16 2021, the SRI platform was officially launched and since then it has been possible for private and public actors to take part in the platform and apply it to properties and buildings (European Commission, 2021), which is what this study aims to do.

3. Methodology

This thesis will utilize a case study approach, which is a qualitative research method that involves in-depth investigation of a particular system or case. Case study methodology is a qualitative research approach that involves an in-depth investigation of a particular phenomenon, system, or case. According to Yin (2018), a case study is a "research strategy that involves empirical investigation of a contemporary phenomenon within its real-life context" (p. 14). Denzin and Lincoln (2018) describe case study research as a "holistic, in-depth exploration of a single bounded system or case (or a few closely-related cases) that relies on multiple sources of evidence" (p. 9).

This thesis will as mentioned use such a research method to explore which potential areas at Campus Varberg have room for energy saving measures, using the Smart Readiness Indicator from the European Commission. There is data available on topics such as energy usage and system installations, in addition to various contact persons who are responsible for the maintenance of the facility, such as facility managers and the company who installed the building control system.

Some of the data, such as construction plans, can be obtained from local authorities. The energy declaration can be given from the Swedish authority, Boverket (Boverket, n.d.). Information regarding system installations is a necessity in order to complete the Smart Readiness Indicator. Expert assistance will be utilized in the form of an unstructured interview. Because the information that the thesis requires comes from the SRI investigation, rather than the general knowledge from our expert, it made sense to have an unstructured interview where we simply went over the SRI documentation and had the expert explain how the system functioned on several topics. Lastly, energy audits will be given out from the facility owners.

The data analysis is quite straightforward. It will be conducted with a thematic analytical approach, which in other words means looking for patterns and themes within the data. Looking through the data several times is to avoid missing certain aspects which may prove to be crucial for the final results. The analysis will be conducted with the focus on finding potential areas for energy saving measures, ideally some sort of realism in regard to economic and technical factors should also be considered in order to provide something of value for the facility owners, Varberg Fastigheter AB.

The validity of the thesis can be said to be sufficient, because it utilizes a standardized framework namely the SRI tool, to receive the results. In addition to this, the use of energy audits are a commonly used method for evaluating energy performances and potential areas of improvements, which further improved the validity. Because of the involvement of various companies such as System Installation and Varberg Fastigheter AB, who both have a strong relation to the facility and its control system, but also have expertise in various system installations, the reliability should become sufficient. Their knowledge can also help to ensure that the data that has been gathered and analyzed seem accurate. Their involvement also allows for repeated reviews of the data, in addition to reviewing the derived results to ensure credibility.

To conclude, the methodology in the thesis will provide a thorough and comprehensive approach to exploring the potential areas for energy saving measures using a case study approach with the Smart Readiness Indicator. The use of multiple data sources, a thematic analysis and iterative approach, and measures to ensure validity and reliability will enhance the quality of the findings and contribute to the broader field of energy-saving initiatives that comes from this thesis.

3.1. Method

3.1.1 Smart Readiness Indicator (SRI) - A tool to assess buildings by the European Commission.

As mentioned previously, the SRI is a tool that aims to measure the smart readiness of buildings, based on various parameters such as energy efficiency, thermal comfort, and indoor air quality. Another way of describing it, would be that the SRI measures the ability of a building to use new technologies and to adapt to the changing energy landscape. Following the European Commission (2021), the steps used to calculate a building's SRI score can be summarized into the following:

- Step 1 - Identify the building type and usage
- Step 2 - Find and gather data on the buildings specific characteristics
- Step 3 - Determine the so-called “weighting factors”.
- Step 4 - Calculate the performance score for each predetermined parameter.
- Step 5 - Calculate the final SRI score.

Below is a more in-depth description of how to perform the 5 steps listed above.

Step 1: Identify the building type and usage

As with most energy saving measures, it is important to identify the building type and use. Because the SRI provides different calculation methods based on either residential or non-residential buildings. It also differentiates between the various usages of the buildings, such as offices, schools, & living areas.

Step 2: Find and gather data on the buildings specific characteristics

Next up is gathering data on the building characteristics. This includes but is not limited to, building envelope, HVAC system & lighting. This type of data can be obtained from documents such as building plans, energy audits, performance certificates, and other similar sources.

Step 3: Determine the so-called “weighting factors”

The SRI calculations use something called the weighting factors. The weighting factors are based on professional opinions, and determine the relative importance of the various parameters used in determining the smart readiness of the buildings. It is therefore not uncommon for them to vary depending on the building type and usage. As an example, the

HVAC system might be weighted higher than a lighting control system, as energy consumption from this category is a major contributor to buildings total consumption, as mentioned previously.

Step 4: Calculate the Performance Scores for each predetermined parameter

The performance scores will be calculated by utilizing the pre gathered data from step 2, in coherence with the weighting factors which was determined in step 3. With the help of standardized metrics, the performance scores may be calculated with regards to the specific building characteristics. Such a metric could be the energy efficiency score, which may be based on the energy consumption per square meter, or per occupant.

For example, if we look at a control system for heat demand, we can see that no automatic control would be given the lowest score (0), whereas a system with individual room control with communication and occupancy detection would be given the highest functionality score (4).

Step 5: Calculate the final SRI score.

Finally, we may finish our calculations with the final SRI score. This is made by combining the performance scores for all our parameters. The SRI score has a range between 0 and 100, with high scores representing a high level of smart readiness.

3.1.2 Formulas & Equations

Equation (1) shows how to calculate the area of a tilted roof, where $\boldsymbol{\alpha}$ is the tilt angle.

(1) $$\frac{Width\ of\ roof\ [m]}{cos(\boldsymbol{\alpha})} \cdot length\ of\ roof\ [m] = Area\ of\ roof\ [m2]$$

Equation (2) shows how to calculate the expected amount of kWp we can expect to install on the roof, depending on the chosen solar panel.

(2) $$\frac{Roof\ area\ [m2]}{Area\ of\ chosen\ panel\ [m2]} \cdot Effect\ of\ panel\ [W] = Wattpeak\ [Wp]$$

Equation (3) gives us the yearly production by multiplying the Wattpeak gained from equation (2), with the kWh/kWp value given from PVGIS data, taken over our specific location.

(3) $$[kWp] \cdot \approx \frac{[kWh]}{[kWp]} = yearly\ production\ of\ kWh$$

The equations above were given by Fredric Ottermo, who is a senior lecturer for the school of business, innovation and sustainability, at Halmstad University.

4. Results following the SRI

Step 1 of SRI: Identifying our building and its usage.

The property Campus Varberg is a facility where education is conducted and consists of a wide range of both programs and courses in the areas of business, health, IT and design. The property is centrally located in the coastal town of Varberg, which is known for its rich cultural heritage and that it is a vibrant community. The relevant property that this thesis focuses on consists of up to date facilities such as libraries, laboratories and classrooms. It also has a large auditorium, conference rooms and a cafeteria. The property is a modern environment and provides good educational opportunities, designed so that students gain good opportunities to complete their education in the best possible way. Campus Varberg is a learning center, which means that it is part of the University of Halmstad, but it also collaborates with other educational institutions around the region, such as Chalmers University of Technology and the University of Gothenburg. This creates great opportunities to take part in and learn from experienced researchers and professors who are very knowledgeable in their specific fields. A major focus is placed on themes such as innovation, sustainability and entrepreneurship, with hopes to help prepare the campus students for successful careers in a world with an increased global economy. Overall, Campus Varberg can be said to be a modern learning center where students are offered a good learning experience in a city with development (Campus Varberg, n.d.).

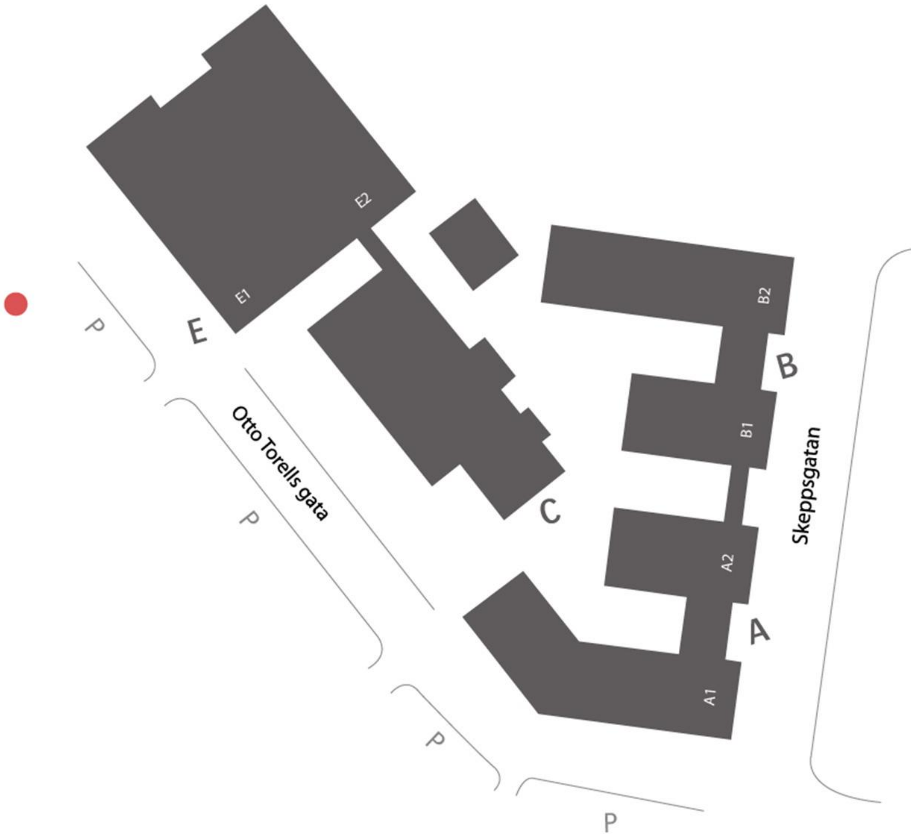


Figure 4. Map of the properties Campus Varberg owns, (Campus Varberg, 2023).

Step 2 of SRI: Finding data on Campus Varbergs building characteristics.

The general data regarding energy use in Sweden can be found in the so called energy declarations. Such declarations are valid for a time period of 10 years, before they need to be updated again (Boverked, n.d.). In addition to the energy declarations, one may find useful data from so called energy surveys. However, not all companies are required to create such surveys, and depending on the specific circumstances they may be difficult to gain access too. Lastly, relevant information about the structural set up of the buildings may of course be taken from blueprints, which in Sweden are often accessible from the municipalities. In order to interpret the values taken from the sources above, it is good to have a large sample size of similar buildings to compare them too. Akademiska Hus is a facility owner in Sweden who owns several large university campuses, and have shared some average values of their buildings energy performances. The values given by Akademiska Hus include operational energy usage, which is not the case for the standardized way of describing energy performances in energy declaration documents. As such, the values have to be amended so that the comparison becomes reasonable.

Building C & E: Library and Server room.

Building C is the campus location for the server room, while building E is the campus library. As seen by looking at figure 5, 6 and 7, house E has a lot of windows facing south west and north west. According to the property and energy manager on site, they have had issues over the years with temperature being too high during spring and summer time due to irradiation, whereas during winter, it becomes too cold.

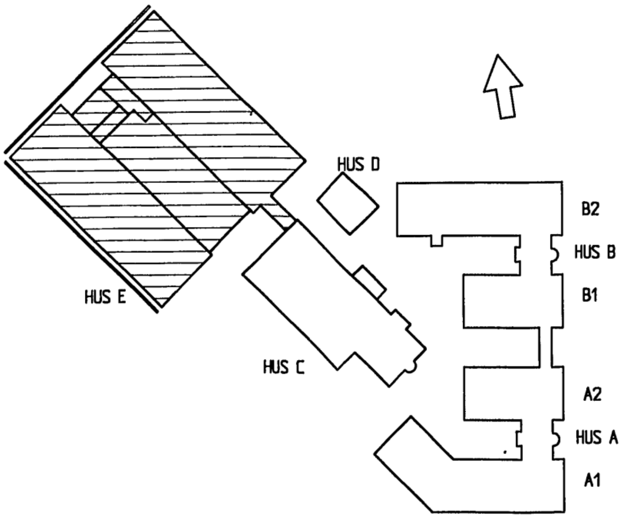


Figure 5. Property with an arrow facing north.

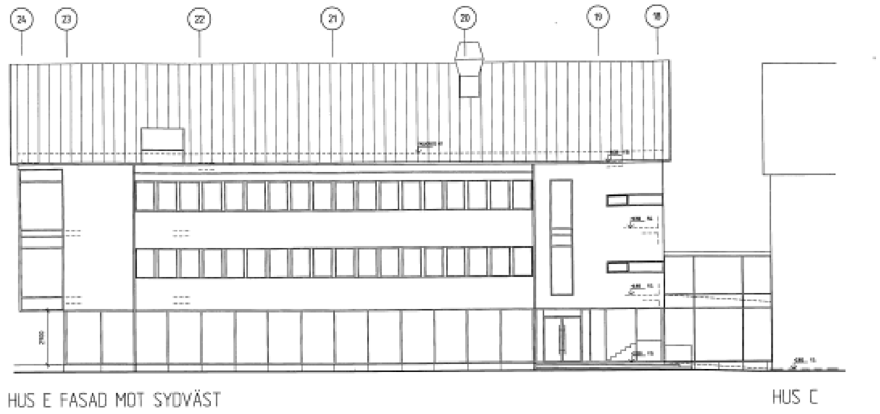


Figure 6. Building E’s facade facing south west.

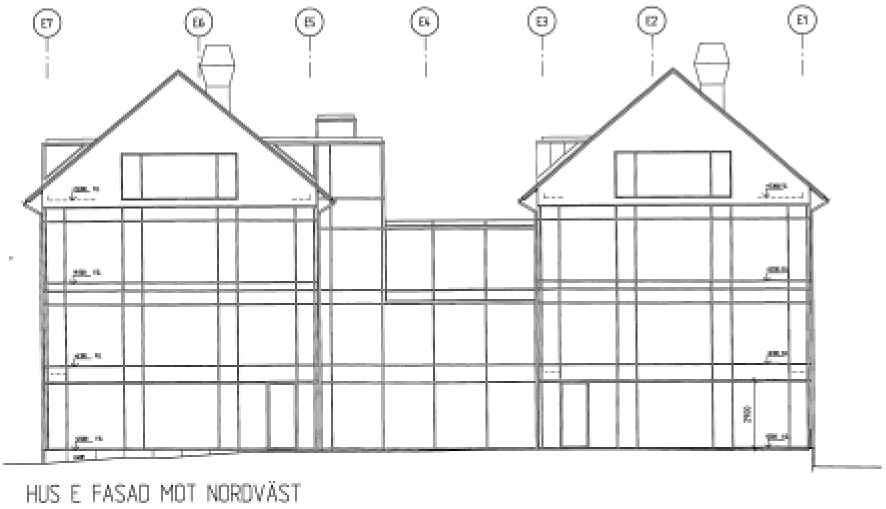


Figure 7. Building E’s facade facing north west.

The supplied heat comes from a district heating network, and is distributed throughout both building C and E via waterborne underfloor heating. Everything is centrally controlled by a main pipeline, with fixed adjustments for every loop. A few rooms also have electricity driven heat fans and radiators. There is also a separate heating circuit installed for the ventilation units. There are gauges for heating, ventilation and sanitation in building E. As for the hot water, it is also delivered by the district heating network, with a circulation unit running at all times. In the computer and auditory rooms, comfort cooling units have been installed, where the excess heat gets transferred into the heat distribution network during winter times, and into cooling towers during summer.

A coolant cooler unit is installed which utilizes the lower night temperatures in correlation with the underfloor piping heating network to chill the joists down. The ventilation units may also be used during the night to help cool the buildings down during summer. There are also separate cooling units for the server room, and as mentioned previously to the auditory and computer rooms. Additionally, there are also units which provide post-cooling via the ventilation system to several lecture rooms in building E.

Building C uses a FTX unit, which supplies the entire building except the restaurant with a supply temperature between 17 - 20 degrees depending on the needs. There is also a rotary heat exchanger combined with evaporative cooling, and some rooms have forced ventilation. As for the restaurant, also located in building C, it is also equipped with a FTX unit, but has a supply temperature of 16 to 19 degrees depending on its needs. A plate heat exchanger is installed and waterborne cooling is used.

Similarly to building C, building E is also equipped with a FTX ventilation system. The delivered temperature varies between 15 and 20 degrees depending on the outdoor temperature curve. A rotary heat exchanger with evaporative cooling is installed. Some rooms have forced ventilation, and a few even have post-cooling batteries with waterborne cooling.

The system installations mentioned above are taken from the energy survey description which was done in 2013. Since then the facility managers have worked on improving the system by doing the following:

- Worked with optimizing the active times of ventilation and lighting.
- Limited the run time of the coolant coolers. Instead using frequency controlled cooling fans that should hopefully lead to quieter operation and lower energy consumption.
- Lastly, attempts have been made to get a more specific zone control of the waterborn heat delivery system, but it has been proved to be quite complex. There is however potential here according to the facility manager.

Figure 7 explains the energy declaration for building C and E. The operational energy consumption is almost as high as the entirety of energy used for heating and hotwater which is likely due to the server halls in building C which are used for the entirety of campus. When comparing buildings with similar activities and usages, the most appropriate action would be to take the energy performances of both and see how it varies. As seen in the declaration, buildings C and E have a combined energy performance of 107 kWh/m^2 per year. Unfortunately, the values provided by Akademiska Hus have their operational energy demands included in the energy performance calculations. In building C, there is a kitchen facility as well as a server hall that is being used by the entire campus. Therefore, it would not be reasonable to adjust the energy performance values for building C and E alone. Instead, the entire Campus Varberg shall be included to create values that are appropriate for a comparison of similar facilities. Campus Varberg does not have laboratories with high electrical demanding equipment, so those have been sorted out from the data provided by Akademiska Hus. As it turns out, Campus Varberg has an energy performance of approximately 187 kWh/m^2 per year, without any laboratories. In comparison, Akademiska Hus uses about 105 -

120 kWh/m^2 per year for facilities without laboratories, and 177 kWh/m^2 per year, if including all facilities with laboratories and heavy electrical equipment (Wik, 2023).

Energianvändning

Verklig förbrukning
Vilken 12-månadsperiod avser energiuppgifterna? (ange första månaden i formatet ÅÅMM)
1212 – 1311

Beräknad förbrukning
Beräknad energianvändning anges för nybyggda/andra byggnader utan mätbar förbrukning och normalårskorrigeras ej
☐

Hur mycket energi har använts för värme och komfortkyla angivet år (ange mätt värde om möjligt)?
Angivna värden ska inte vara normalårskorrigerade

			Mätt värde	Fördelat värde
Fjärrvärme (1)	350760	kWh	○	●
Eldningsolja (2)		kWh	○	○
Naturgas, stadsgas (3)		kWh	○	○
Ved (4)		kWh	○	○
Flis/pellets/briketter (5)		kWh	○	○
Övrigt biobränsle (6)		kWh	○	○
El (vattenburen) (7)		kWh	○	○
El (direktverkande) (8)	27000	kWh	○	●
El (luftburen) (9)		kWh	○	○
Markvärmepump (el) (10)		kWh	○	○
Värmepump-frånluft (el) (11)		kWh	○	○
Värmepump-luft/luft (el) (12)		kWh	○	○
Värmepump-luft/vatten (el) (13)		kWh	○	○
Energi för uppvärmning och varmvatten[1] (Σ1)	377760	kWh		
Varav energi till varmvattenberedning	67500	kWh	○	●
Fjärrkyla (14)		kWh	○	○

Omvandlingsfaktorer för bränslen i tabellen nedan gäller om inte annat uppmätts:

Eldningsolja	10 000 kWh/m^3
Naturgas	11 000 kWh/1 000 m^3 (effektivt värmevärde)
Stadsgas	4 600 kWh/1 000 m^3
Pellets	4 500-5 000 kWh/ton, beroende av träslag och fukthalt

Källa: Energimyndigheten
För övriga biobränsle varierar värmevärdet beroende av sammansättning och fukthalt. Det är expertens ansvar att omräkna bränslets vikt eller volym till energi på ett korrekt sätt.

Övrig el (ange mätt värde om möjligt)
Angivna värden ska inte vara normalårskorrigerade

			Mätt värde	Fördelat värde
Fastighetsel[2] (15)	137000	kWh	○	●
Hushållsel[3] (16)		kWh	○	○
Verksamhetsel[4] (17)	385039	kWh	○	●
El för komfortkyla (18)	12000	kWh	○	●
Tillägg komfortkyla[5] (19)	0	kWh		
Byggnadens energianvändning[6] (Σ3)	526760	kWh		
Byggnadens elanvändning[7] (Σ4)	176000	kWh		

Finns solvärme? ○ Ja ● Nej
Ange solfångararea: m^2
Beräknad energiproduktion: kWh/år

Finns solcellssystem? ○ Ja ● Nej
Ange solcellsarea: m^2
Beräknad elproduktion: kWh/år

Ort (graddagar) Varberg	Normalårskorrigerat värde (graddagar) 500927 kWh	Ort (Energi-Index) Varberg	Normalårskorrigerat värde (Energi-Index)[8] 545931 kWh
Energiprestanda 107 kWh/m^2,år	...varav el 35 kWh/m^2,år	Referensvärde 1 (enligt nybyggnadskrav) 100 kWh/m^2,år	Referensvärde 2 (statistiskt intervall) 123 – 184 kWh/m^2,år

Figure 8. Energy Declaration for buildings C and E.

However, the declaration is from 2013, whereas Akademiska Hus provided recent, up to date information. If we look at the energy used during 2022 by contacting the energy provider for Campus Varberg, we see that the actions listed before have managed to lower their energy usage somewhat. In total during 2022, they used 691,27 MWh from district heating, and 673,11 MWh in electricity. With these new values, we see that Campus Varberg has managed to improve their energy performance down to 151,4 kWh/m^2 per year. Still not great, but at least it is not above the heavy electrical laboratory facilities.

Step 3 of SRI: Determine the weighting factors

This thesis uses the standard weighting factors provided by the document handed out by the European Commission, with the preferred service catalog B which is the slightly more advanced version.

Step 4 & 5 of SRI: Calculating performance scores and final SRI.

After filling in the documents provided by the European Commission, the university campus in Varberg managed to get a total SRI score of 39,3 %. For further details regarding the calculation section of the score, check Appendix 1 at the end of the thesis.

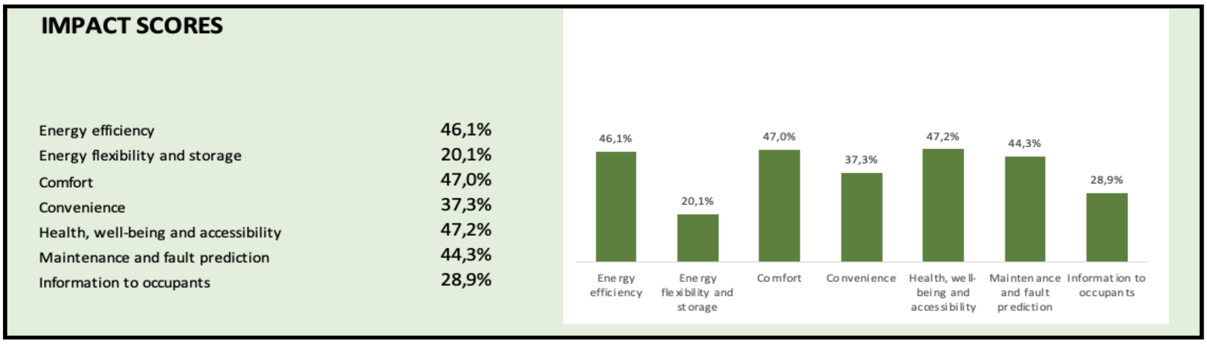
Evaluation of the SRI results.

In this chapter we will do a relatively simple evaluation and analysis of the results granted by the SRI calculations.

TOTAL SRI SCORE	**35,1%**	**SRI CLASS**	**Between 35% and 50%**

Figure 9. The current SRI score.

The first and perhaps easiest fact to determine, is that although a final score of 35,1 % is by no means a bad score given the age of the building in coherence with the advanced technologies required, the fact remains that there are plenty of potential improvements that can be made.



IMPACT SCORES

Energy efficiency	46,1%
Energy flexibility and storage	20,1%
Comfort	47,0%
Convenience	37,3%
Health, well-being and accessibility	47,2%
Maintenance and fault prediction	44,3%
Information to occupants	28,9%

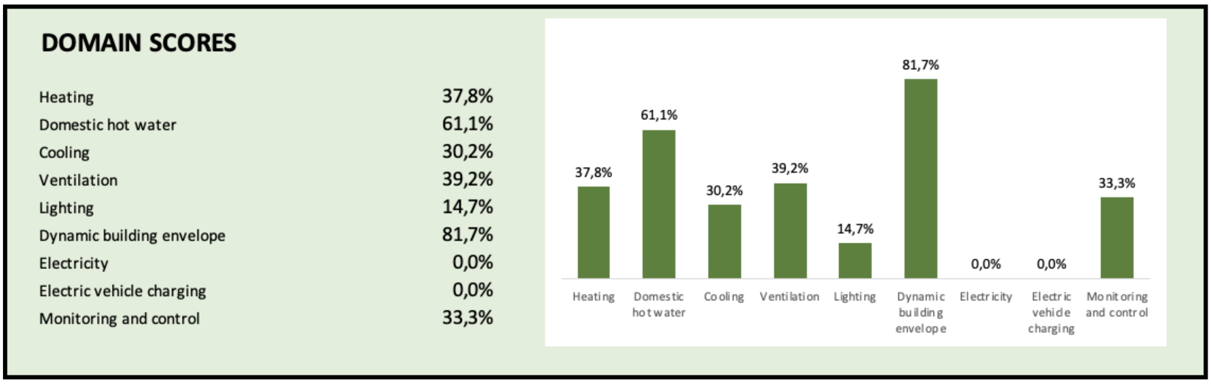
Figure 10. The current impact score.

By looking at the *impact scores* we can get a rough idea of what led up to the final results. The impact scores are originally derived from three key smart readiness functionalities according to the European commission.

- ➢ Optimize energy efficiency and overall in-use performance
  - ○ Energy efficiency
  - ○ maintenance and fault predictability
- ➢ Adapt their optimisation to the needs of the occupants
  - ○ comfort
  - ○ convenience
  - ○ health, well being & accessibility

        - information to occupants
    - Adapt to signals from the grid (energy flexibility).
        - Energy flexibility & storage

The strongest outliner here is clearly the energy flexibility and storage, which is the subcategory for adapting to signals from the grid. However, the facility used district heating systems and hence have no local energy storage, making grid flexibility difficult to achieve because there is no buffer present which may be charged during low cost hours. The campus also has no local electricity production that could have charged a battery or arguably communicated with the grid to sell electricity during peak hours. Regardless, it would be interesting to 1. See how much installation of solar panels would cost and how long the return of investment would take, given the prime coastal location with plenty of rooftops facing south, and 2. how such an installation would affect the currently lacking energy flexibility and storage impact result.

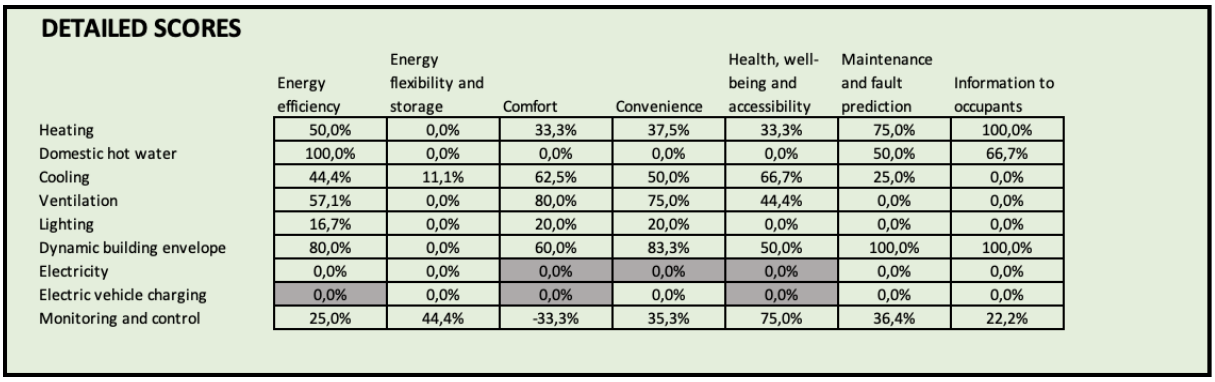


DOMAIN SCORES

Heating	37,8%
Domestic hot water	61,1%
Cooling	30,2%
Ventilation	39,2%
Lighting	14,7%
Dynamic building envelope	81,7%
Electricity	0,0%
Electric vehicle charging	0,0%
Monitoring and control	33,3%

Figure 11. The current domain score.

In addition to the impact scores there are also the so-called *domain scores,* which are arguably more interesting to look at from a technological perspective. These scores are determined by evaluating certain aspects of the building, such as the HVAC or building control systems. The scores offer an overview of the building's performance in each of the areas seen in image 9.



DETAILED SCORES

	Energy efficiency	Energy flexibility and storage	Comfort	Convenience	Health, well-being and accessibility	Maintenance and fault prediction	Information to occupants
Heating	50,0%	0,0%	33,3%	37,5%	33,3%	75,0%	100,0%
Domestic hot water	100,0%	0,0%	0,0%	0,0%	0,0%	50,0%	66,7%
Cooling	44,4%	11,1%	62,5%	50,0%	66,7%	25,0%	0,0%
Ventilation	57,1%	0,0%	80,0%	75,0%	44,4%	0,0%	0,0%
Lighting	16,7%	0,0%	20,0%	20,0%	0,0%	0,0%	0,0%
Dynamic building envelope	80,0%	0,0%	60,0%	83,3%	50,0%	100,0%	100,0%
Electricity	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Electric vehicle charging	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Monitoring and control	25,0%	44,4%	-33,3%	35,3%	75,0%	36,4%	22,2%

Figure 12. The current detailed score.

Lastly we have the *detailed scores* which essentially are the underlying values which led up to the prior domain scores. If the domain scores lets building owners or operators grasp what areas to focus their attention towards, the detailed scores allows them to further pin-point what specific action would grant the most significant impact on the building's performance.

Looking at the specific detailed scores for campus Varberg, it is clear that electricity and electric vehicle charging are two areas that are non present. Not odd, considering that the facility does not have any electricity production as mentioned previously. In addition to this, we suspect that the impact score for energy flexibility and storage may also benefit strongly by installing solar panels with corresponding storage utilities with incorporated grid communication.

Looking at information to occupants, which had the second worst impact score, there are several domains who do not have any scores at all, indicating that a lot can be achieved in this area with relatively low efforts. One such action could be providing the occupants with more information of the buildings energy usage and performance through real-time displays outside of classrooms in order to raise awareness and encourage energy efficient behavior.

Lighting is yet another area that leaves much to desire, currently only utilizing manual on/off switches with parts of the campus having a sweeping extinction signal. You may currently only adjust the illumination manually if you wish to lower the brightness in the case of sufficient daylight levels. Automatic dimming depending on daylight levels, as well as automatic detection for on/off functions, while still having the option to override manually, would be something that could be looked further into.

Lastly, under the impact score “comfort”, the monitoring and control domain showcases a negative value. It may be that finding the underlying reason for this and adjusting it may benefit the impact score and of course the comfort of the occupants greatly. A starting point may be seeing if a monitoring system for irradiation in coherence with shaders of some sort could be a viable solution. This could positively affect both cooling, monitoring and control, as well as lighting under the comfort section.

So, to summarize the approach moving forward:

- Calculate the cost and effect of solar panel installations
- See how energy storage with grid communication functionalities would affect certain aspects of the buildings’ performance, and indirectly the SRI score.
- Add electrical vehicle charging options with bi-direction charging to the local campus and main electrical grid. This will not affect the energy efficiency, but it may greatly increase the flexibility of the local energy grid at campus.
- Add displays showcasing the current energy used to raise awareness of occupants.
- See how adding detection sensors and daylight level sensors could affect the final SRI score.
- Discover the cause of the negative comfort value and what would be required to adjust it. Additionally, see how this could potentially increase comfort for occupants and the final SRI score.

Once the points above have been completed, a new SRI calculation will take place, adjusting for these changes, and thereafter be compared against the current one.

5. Introductory study on possible measures to take

5.1 Solar panels, energy storage & EV charging

So, let us discuss and analyze some literature on how solar panels, energy storage and lastly EV charging could affect the impact score regarding energy flexibility and storage.

5.1.1 Electric vehicles (EVs) with bi-directional charging.

The charging technology related to electric vehicles have improved significantly over the years, and implementing it on the university campus may provide several benefits. The perhaps most obvious one would be the reduction of fossil-fuel dependent vehicles, by instead encouraging EVs with new charging infrastructure, and as a result lowering the universities carbon emissions. However, the focus of this change should not be on the carbon emissions, but on the energy flexibility and energy storage that can be satisfied via bi-directional charging stations. Bi-directional charging means that the EV may not only receive energy, but also to feed energy back into the grid or a building, essentially making the connected EVs into a mobile energy storage. This is often referred to as vehicle-to-grid or V2G and can provide several benefits to the grid and EV owners (Han et al., 2019). With such technology it is possible to help balancing the grid during peak demand periods, often referred to as peak shaving, but also frequency regulation and voltage support (Engleberger et al., 2021). In addition to this, it also benefits renewable production installations by allowing excess energy to be stored during the day and then as mentioned discharged when demand rises, or when the production is low. There are multiple studies highlighting the potentials described regarding bi-direction charging. For one, V2G can reduce the total cost of ownership of EVs by enabling them to participate in energy markets and earn revenue from providing grid services (Kempton & Tomic, 2005). Engleberger et al. (2021) also suggested an optimization algorithm that allows electric vehicles with bi-directional charging capabilities to act as mobile energy storage systems in order to maximize the possible revenue from various markets, such as the energy market, ancillary services market and capacity markets. The technology may also enhance the capabilities to reduce carbon emissions from transportation further, by enabling the integration of renewable sources into the power supply (Geske & Schumann, 2018). Geske and Schumann (2018) also studied the willingness to participate in vehicle-to-grid programs amongst EV owners, and discovered that many are willing to do so, given that there are positive incentives provided.

5.1.2 Solar panels

Solar energy is a renewable energy source, which may help supply the university campus with clean power. By collecting energy during the day, solar panels can lower the current reliance on the grid. However, the amount of generated energy may vary throughout the year and days, depending on weather factors and installations positions of the panels. There are a lot of things to consider if one wishes to maximize the benefits from solar benefits, design and installation of the panels being one such thing. Albeit a very different country in regards to the weather, Ting et al. (2020) conducted a feasibility study on the implementation of solar panels for a campus in Malaysia. The installation could be a cost-effective solution if one wished to reduce their carbon emissions. Highly irradiated areas with proper orientation and tilt angle of the panels should be considered to maximize the energy production. Furthermore, advanced forecasting models have the potential to improve the performance of solar panels. In a study made by Vignola et al (2021), various methodologies and tools for solar radiation and photovoltaic production forecasting were reviewed. It was discovered that statistical models and machine learning algorithms could accurately and effectively predict solar irradiation and the following energy production. This may help in optimizing the usage of solar energy as well as lowering the reliance on the grid further.

5.1.3 Electrical or hybrid energy storage

Energy storage may support renewable energy sources such as the solar panels mentioned previously, by helping them overcome the issue related to their irregular production. By storing any excess energy generated during high production, to then discharge when production is low, energy storage may help with increasing the stability of the grid, but also to lower the demand for possible fossil fueled peaker plants.

There are many different types of energy storage available such as battery energy storage systems (BESS), hydrogen storage or thermal energy storage (TES). Because of its high efficiency and flexibility, BESS is one of the more common storage solutions. Alsaidan et al. (2018) proposed a comprehensive model for optimizing the size of battery energy storages used in microgrid applications. The model aims to find the optimal size of the BES with regards to minimizing cost of energy supply, while at the same time making sure that the system can meet the demand for electricity. Likewise, Koskela et al. (2019) proposed a method for sizing batteries and photovoltaic panels based on electricity costs in residential buildings. A mathematical model took electricity generation and consumption profiles, technical constraints of the system and lastly energy prices into consideration, with results showcasing that the optimal size of battery and panels can be achieved if consideration are taken to the electricity tariff structure, the equipment technical parameters, and electrical demand patterns.

By integrating hybrid systems with renewable energy sources and storage solutions, one may further improve the efficiency of the system as a whole. Liu et al. (2021) proposed a hybrid system consisting of renewable electricity and storage of there of, in addition to hydrogen production and storage in combination with hydrogen vehicles connected to the grid similarly as the EVs mentioned previously. According to Liu et al. (2021), the results made it clear that hybrid systems can achieve a high level of independence and thus lowering the reliance on the grid, while also providing a multitude of grid services and economical benefits. Although hydrogen might not be a subject that has been explored prior in this project, it could be that the installation of another system, namely thermal energy, could provide similar positive results for campus varberg. Currently struggling with energy flexibility, having a local TES unit which may supply the building with either responsive heating or cooling depending on grid signals would be something to consider.

To summarize, by implementing local and renewable energy production such as solar cells and possibly also wind turbines, paired with hybrid storage solutions such as batteries and TES, improvements upon the energy flexibility and storage impact scores may be achieved for campus Varberg. Integrating these solutions with the flexibility from vehicle to grid technology can further enhance the efficiency of the system, and accelerate campus varbergs change into a energy sustainable facility.

5.2 Calculations regarding solar panels & electrical storage.

5.2.1 Profitability of solar panels installation on building C & E.

The roof area of building C & E is roughly 570 m2 and 485 m2 respectively. There are two separate roofs on building E, hence a total roof area of 970 m2. We would ideally only want to install solar panels facing south for highest efficiency possible, hence only a portion of the total roof area will be utilized. There is also a slope of 40 degrees angle to take into account.

$$Width\,facing\,south,\ Building\,C\ =\ \frac{14}{2} = 7m$$

$$Roof\ Area\,facing\,south,\ Building\,C\ =\ \frac{7}{cos(40)}\cdot 40.5\ =\ 370\,m2$$

$$Width\,facing\,south,\ Building\,E\ =\ \frac{Total\,Width}{2}\ =\ 6.75\,m$$

$$Roof\ Area\,facing\,south,\ Building\,E\ =\ \frac{6.75}{cos(40)}\cdot 36\ \cdot 2\ =\ 634\,m2$$

$$Total\,roof\ area\,facing\,south\ \approx\ 1000\,m2$$

According to PVGIS, with an azimuth angle of roughly 55 degrees and a slope of 40 degrees, campus Varberg can expect a yearly PV production of ~910 kWh per kWp installed.

Going through a few options, a suitable panel such as SoliTek -Blackstar 365W, has as the name suggests a peak production of 365 Watt. The dimensions of this specific panel are 1782 x 1061 mm or 1,9 m2.

The calculations for expected production hence becomes:

$$\frac{1000}{1.9}\cdot 365\ \cdot 10^{-3}\ =\ 192\,kWp$$

$192\ \cdot 910\ \approx\ 175000\,kWh\ =\ 175\,MWh$ yearly production.

According to the energy declaration, or figure 5, the facility used a total of 561 MWh of electricity, if one were to include the operational values. The expected production does clearly not measure up to the final consumption, making additional investments less fruitful. There simply will not be enough leeway for any intelligent system paired with a battery to make any sort of smart decisions with regards to grid services or energy market in general, because all the production will be consumed by the building's energy demand most of the time. Now this is not strange, considering that there is a kitchen facility with heavy electrical demands in addition to the server hall. But it does mean that there is less incentive in general to make such heavy investments towards solar panels, at least in the argument for a smart building feature.

5.2.2 Profitability of solar panels installation on building A & B.

The sum of the roof area which will carry solar panels on building A & B is roughly 930 m2. However, 105 m2 has an azimuth angle of 55 degrees, the same as building C and E, whereas the remaining roof area has an azimuth angle of only 5 degrees. The slope is the same as before on all roof areas, 40 degrees.

$$The\ width\ of\ both\ building\ A\ and\ B,\ facing\ south\ =\ \frac{12.4}{2} = 6.2m \rightarrow \rightarrow$$

$$Total\ Roof\ Area\ facing\ south,\ 5\ degrees\ azimuth\ =\ \frac{6.2}{cos(40)}(22\ \cdot\ 3\ +\ 36)\ =\ 825\ m2$$

$$Total\ Roof\ Area\ facing\ south,\ 55\ degrees\ azimuth\ =\ \frac{6.2}{cos(40)} \cdot\ 13\ =\ 105\ m2$$

For the area which had an azimuth angle of 55 degrees, the value of yearly PV production will be the same as before, ~910 kWh per kWp installed. However, for the panels which only have an azimuth angle of 5 degrees, the production will be slightly higher, coming in at roughly 1040 kWh per kWp installed.

Using the same panels as before, the expected production can be seen in the calculations below.

$$5\ degrees\ azimuth \rightarrow \frac{825}{1.9} \cdot\ 365\ \cdot\ 10^{-3}\ =\ 158.5\ kWp$$

$$55\ degrees\ azimuth \rightarrow \frac{105}{1.9} \cdot\ 365\ \cdot\ 10^{-3}\ =\ 20.2\ kWp$$

$158.5\ \cdot\ 1040\ +\ 20.2\ \cdot\ 910\ \approx\ 183\ MWh$ yearly production.

If we were to combine the two expected productions, Campus Varberg could expect a yearly gain of roughly 358 MWh. Comparing this to the use of electricity in 2022 which was 673 MWh, they could expect to fulfill roughly 53 % of their electrical demand with the help of these solar panel installations.

The question of “is it worth installing a battery” should not be entirely ruled out while reading this thesis, because a large amount of production will happen during the summer months, which can be seen in figure 10 below. Combined with the fact that a lot of the facilities are not in use during summer, there may be a possibility to store and sell a portion of produced electricity during these few months. To do a proper analysis, data on the monthly electrical consumption would be required from Varberg Fastigheter AB. So, moving forward with this thesis, the assumption made in 6.2.1, that it is most likely not worth it to install a battery for Campus Varberg, will still hold true.

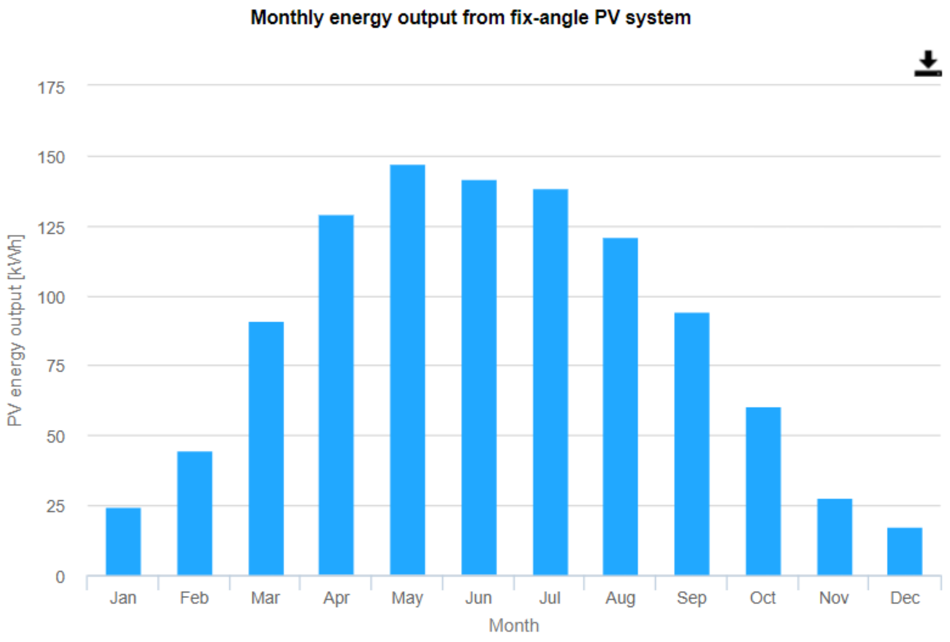


Figure 13. PV energy output at 40 degrees angle and an azimuth angle of 5 degrees. Provided by the PVGIS tool (Joint Research Centre of the European Commission, n.d.).

5.3 Detection sensors, daylight sensors & Increased comfort in buildings.

A major part of increasing energy efficiency and improving comfort levels in buildings can be met by the installation of detection and daylight sensors. Detection, or occupancy sensors, are as the name suggests used to detect the presence or absence of people in a room. They may be used to control lighting and HVAC systems in hopes of reducing unnecessary energy consumption, as the systems may be turned off when a room is unoccupied.

Li et al. (2020) reviewed energy-efficient lighting control strategies, which highlighted occupancy detectors importance in the pursuit of improving energy efficiency. Furthermore, the article provides insight on how such sensors can be optimized in order to achieve the highest energy savings and comfort levels. Similarly, daylight sensors track the level of natural light and help by adjusting the artificial lighting in a room accordingly. This may also lead to energy savings, because the artificial light may be tuned down or turned off completely when there is sufficient natural light available. Additionally, daylight sensors can be optimized further by integrating them with the other building systems, most notably shading and HVAC systems, in order to gain the most optimal energy savings and occupant comfort (Chen et al., 2021).

Building further upon the topic of building automation systems, Wen and Zhao (2021) have done an in-depth review which highlights the technologies and sensors that may be a part of such systems, including the above mentioned detection and daylight sensors. Such sensors may also play a part in control strategy optimization. Raftery et al. (2020) argued for the usage of multi objective evolutionary algorithms in order to optimize the lighting and HVAC systems in net zero energy buildings. The article focused on the use of such sensors in the optimization process, and provides insights on how one may gain the best energy savings and occupant efforts by using the detection and daylight sensors.

As mentioned at the beginning, these types of sensors play a crucial role for anyone who wishes to improve their energy efficiency but at the same time also increase occupant comfort. Even better results may be achieved if one were to integrate the sensors with other building systems and control strategies.

5.4 Increasing the comfort in SRI investigation

After going through the SRI calculation sheet the reason for a negative comfort result under the “monitor and control” domain was discovered. As it turns out, having a demand side management control system without the possibility to manually regulate or override it will have a negative effect on occupants' comfort levels, according to the SRI spreadsheet. Furthermore, in a study conducted by Gao et al. (2021), they concluded the exact same thing as the spreadsheet showcased. More specifically, demand side management (DSM) strategies may increase buildings energy efficiency while maintaining user comforts. However, the article also emphasized how crucial it is for occupants and facility managers to override the system. The reason why it is important is to avoid the potential conflict between the occupants comfort levels and the potential energy savings, especially during harsh weather conditions, such as extreme cold or heat waves.

As such this is the primary area to adjust for campus varberg if they wish to have a quick fix for some of their current comfort issues. In addition to allowing for manual overrides of the DSM system, changing the runtime setting for heating and cooling system from a timed schedule, into a runtime setting based on building loads could also increase comfort levels. Choi et al. (2018) showcased that heating and cooling strategies based upon building loads can not only improve the indoor thermal comfort, but also reduce energy consumption at the same time. Furthermore, by adding real time data regarding outside weather conditions and occupancy detection, the heating or cooling system may adjust the outputs in order to improve thermal comfort of building occupants. However, the study importantly highlighted as this thesis also has prior, that if such a system is to function properly and effectively, there exists a high demand for accurate occupancy data.

As mentioned prior, and strengthened further by Liu et al. (2019), occupancy based control for lighting may also increase comfort levels of occupants while improving energy efficiency of the facility. The study also emphasized once again, that integrating the occupancy data with other building systems could improve the overall energy performance. .

6. Results after the suggested changes

6.1 Adapting the SRI calculations after suggested changes.

After going through the previous SRI results several subjects in various fields were discussed and analyzed in order to provide suitable changes to Campus Varberg. Within the SRI spreadsheet, the following changes have been made.

Table 1. Changes made in regards to artificial lighting:

Subject	**Functionality level Before**	**Functionality level After**
Occupancy control for indoor lighting	Functionality level 0 Manual On/Off switch	Functionality 3 Automatic detection (auto on / dimmed or auto off)
Control artificial lighting based on daylight savings	Functionality level 1 Manual (Per room / zone)	Functionality 3 Automatic switching

Table 2. Changes made in regards to local electricity production, storage and grid interaction.

Subject	**Functionality level Before**	**Functionality level After**
Reporting information regarding local electricity production	Functionality level 0 None	Functionality 2 Actual values and historical data
Reporting information regarding electricity consumption	Functionality level 0 Not present	Functionality 1 Reporting on current electricity consumption on building level

Table 3. Changes made in regards to the building control system

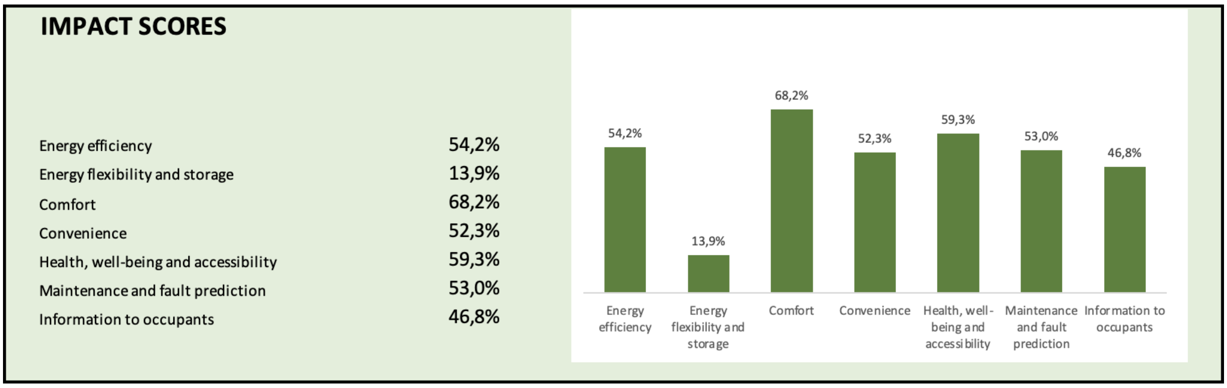
Subject	**Functionality level Before**	**Functionality level After**
Run time management of HVAC systems	Functionality level 1 Runtime setting of heating and cooling plans following a predefined time schedule	Functionality 2 Heating and cooling plant on/off control based on building loads
Occupancy detection: Connected services	Functionality level 0 None	Functionality 1 Occupancy detection for individual functions, e.g. lighting
Override of DSM control	Functionality level 1	Functionality 2

	DSM control without the possibility to override this control by the building user (occupant or facility manager)	Manual override and reactivation of DSM control by the building user

The above mentioned changes have changed the total SRI score for the better by 6.3 %. Interesting is to see how the energy flexibility and storage impact score have gone down despite all the positive changes being made. As it turns out, allowing manual override of the DSM control increases occupant comfort levels from 61.6 % to 68.2 %. However, it also lowers the energy flexibility and storage of our system from 21.8 % down to 13.9 %. If we were to ignore the change, and keep it at functionality level 1 as seen in table 3, our final SRI score would be slightly better, reaching 41.9 % as opposed to the current 41.4 %. It seems to come down to energy efficiency versus occupants comfort levels, where increasing one parameter makes the other slightly less efficient.

TOTAL SRI SCORE 41,4% **SRI CLASS** Between 35% and 50%

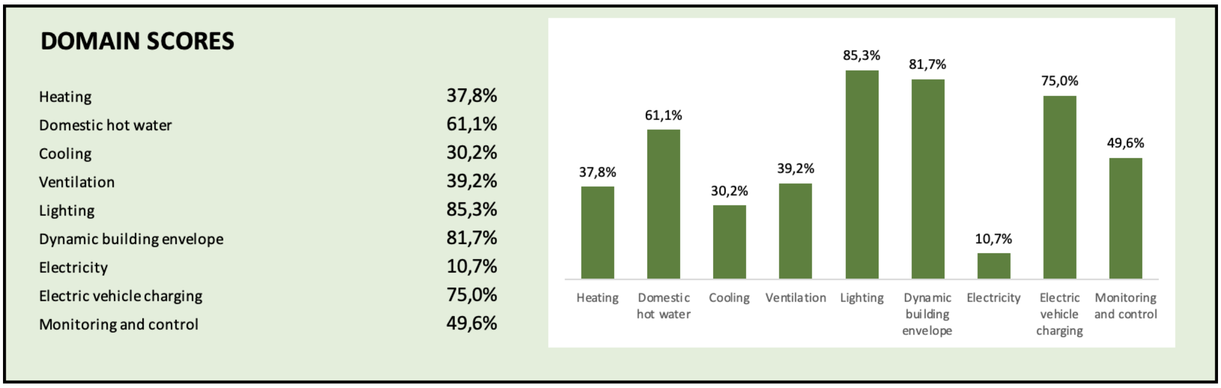
Figure 14. The new SRI score after suggested changes have been implemented.



IMPACT SCORES

Energy efficiency	54,2%
Energy flexibility and storage	13,9%
Comfort	68,2%
Convenience	52,3%
Health, well-being and accessibility	59,3%
Maintenance and fault prediction	53,0%
Information to occupants	46,8%

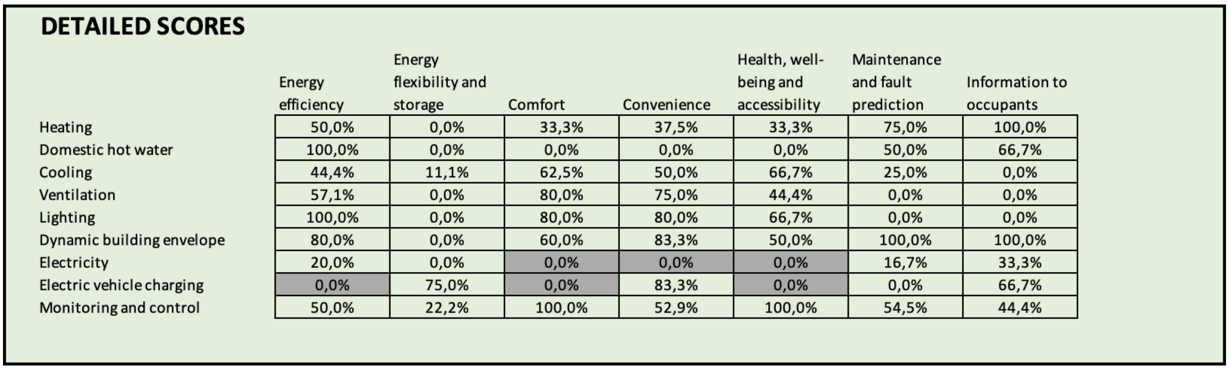
Figure 15. The new impact score after suggested changes have been implemented.



DOMAIN SCORES

Heating	37,8%
Domestic hot water	61,1%
Cooling	30,2%
Ventilation	39,2%
Lighting	85,3%
Dynamic building envelope	81,7%
Electricity	10,7%
Electric vehicle charging	75,0%
Monitoring and control	49,6%

Figure 16. The new domain score after suggested changes have been implemented.



DETAILED SCORES

	Energy efficiency	Energy flexibility and storage	Comfort	Convenience	Health, well-being and accessibility	Maintenance and fault prediction	Information to occupants
Heating	50,0%	0,0%	33,3%	37,5%	33,3%	75,0%	100,0%
Domestic hot water	100,0%	0,0%	0,0%	0,0%	0,0%	50,0%	66,7%
Cooling	44,4%	11,1%	62,5%	50,0%	66,7%	25,0%	0,0%
Ventilation	57,1%	0,0%	80,0%	75,0%	44,4%	0,0%	0,0%
Lighting	100,0%	0,0%	80,0%	80,0%	66,7%	0,0%	0,0%
Dynamic building envelope	80,0%	0,0%	60,0%	83,3%	50,0%	100,0%	100,0%
Electricity	20,0%	0,0%	0,0%	0,0%	0,0%	16,7%	33,3%
Electric vehicle charging	0,0%	75,0%	0,0%	83,3%	0,0%	0,0%	66,7%
Monitoring and control	50,0%	22,2%	100,0%	52,9%	100,0%	54,5%	44,4%

Figure 17. The new detailed score after suggested changes have been implemented.

The building has seen decent improvements comparing the two impact scores, with the exception of energy flexibility and storage which have already been mentioned. Areas which the building is still lacking in can be seen in figure 12. There are a lot of domains that are still at 0 %, and addressing these would obviously increase the final score by a substantial amount.

A clear example would be a change to the current heating system, with regards to grid interaction. It currently sits at the functionality level 0, which has no automatic control. If it instead was changed so that it had a functionality level of 3 which is flexible control via grid signals, the final SRI score would go from 41.4 % up to 53.5 %. The impact score on energy flexibility and storage would go up to 51.3 % with just this one change. However, it does not seem to be very realistic to have a heating or energy system in general to be flexible towards the grid, without having any sort of storage capabilities, either electrical or thermal energy storage.

Table 5. Changes that were not made, but have potential in an ideal scenario.

Domain	**Subject**	**Functionality level Before**	**Functionality level After**
Heating	flexibility & grid interaction	Functionality level 0 No automatic control	Functionality level 3 Heating system capable of flexible control through grid signals (e.g DSM).

7. Discussion & Conclusion

In this thesis on master level, the Smart Readiness Indicator tool from the European Commission has been used to evaluate Campus Varberg, in hopes of finding potential areas where energy saving measures may have the greatest effect. It was discovered that the installation of occupancy and daylight sensors, in correlation with automatic control of the artificial lighting could provide a strong improvement to the lighting domain score. Adjusting the run time of HVAC systems to be demand side based as opposed to the current predetermined time schedule would give only positive results on several parameters. From a comfort perspective, the biggest change that can be made is allowing for manual override of the demand side management. The perhaps biggest discovery from the thesis was how dependent the SRI scores are on the ability to have communication and be adaptable towards the grid. Unfortunately, it is not realistic to be adaptive and flexible without some sort of storage unit installed. When calculating the estimated energy gains from installing solar panels on Campus Varberg, it was noted that the total production would not meet up with the total consumption, and a battery would therefore not be a viable installation. It therefore limits the possible SRI score by quite a large margin. Arguably, the best case scenario would be to reduce energy consumption by fine tuning lighting and HVAC control, until it reaches a point where the installation of solar panels could be made in coherence with an installation of a battery that has grid interaction capabilities. The current Campus Varberg has limited possibilities to be flexible towards the grid, but with a battery or other energy storage installation, this would change drastically, allowing for even more energy saving measures to take place. The thesis has also mentioned the difficulties and benefits of installing charging stations for EVs. However, without a battery installation the Vehicle-to-grid technology also becomes limited. It becomes evident that integrating an energy storage system is both crucial and practically indispensable for achieving a higher SRI score and ultimately creating a more intelligent building. A battery installation should therefore not be ruled out completely. There are two primary arguments for this. First of all this thesis covers a yearly demand and consumption, whereas a monthly based investigation may have given more details and perhaps more incentives in favor of installing some sort of energy storage. Secondly, there are two electrical heavy facilities on Campus Varberg, namely the server hall and kitchen. The server hall could be argued to be a necessity for the functionality of Campus Varbergs daily activities. But outsourcing the kitchen activities, or dividing the electrical demand into two separate entities, could perhaps be the push needed to encourage the installation of the impactful energy storage.

Before the final conclusion of the report, it is worth mentioning that the SRI tool still has a few flaws in the way one can utilize it to evaluate buildings. Similar to what Vigna I. et al (2020) concluded in their article, we also felt that there was difficulty with evaluating certain aspects of the building when the functionality levels differed, or were only available for a portion of the facility. This report therefore strengthens their claim that there is a need for an option to choose a certain floor area covered by the specific technology, or other proposed solutions to the described issue.

To conclude, this thesis on master level aimed to evaluate Campus Varberg using the Smart Readiness Indicator (SRI) tool from the European Commission to identify potential energy-saving measures. The findings emphasized the importance of incorporating occupancy and daylight sensors along with automatic control of artificial lighting to significantly improve the lighting domain score. Additionally, transitioning HVAC systems to demand-side-based run times rather than predetermined schedules would yield positive outcomes across multiple parameters. From a comfort perspective, allowing manual override of demand-side management emerged as a significant change. The thesis revealed a key insight regarding the dependence of SRI scores on adaptability and communication with the grid, highlighting the necessity of energy storage installations to achieve flexibility. While solar panel installation alone did not meet total consumption, coupling it with a battery and grid interaction capabilities would enable a smarter building with increased energy-saving potential. The installation of charging stations for electric vehicles also relied on energy storage capabilities for efficient utilization of Vehicle-to-Grid technology. Furthermore, the thesis suggested that a battery installation should not be disregarded entirely, as monthly-based investigations and dividing electrical demands could provide incentives for impactful energy storage. Enabling the use of a battery would unlock various possibilities, including implementing a grid signal-based heating system, which alone would have improved the SRI score by 12.1%. Lastly, it was noted that the SRI tool inadequately accounted for facilities using district heating instead of heat pumps, which resulted in certain technicalities being outsourced to the district heating company rather than being under direct control, potentially affecting the overall score.

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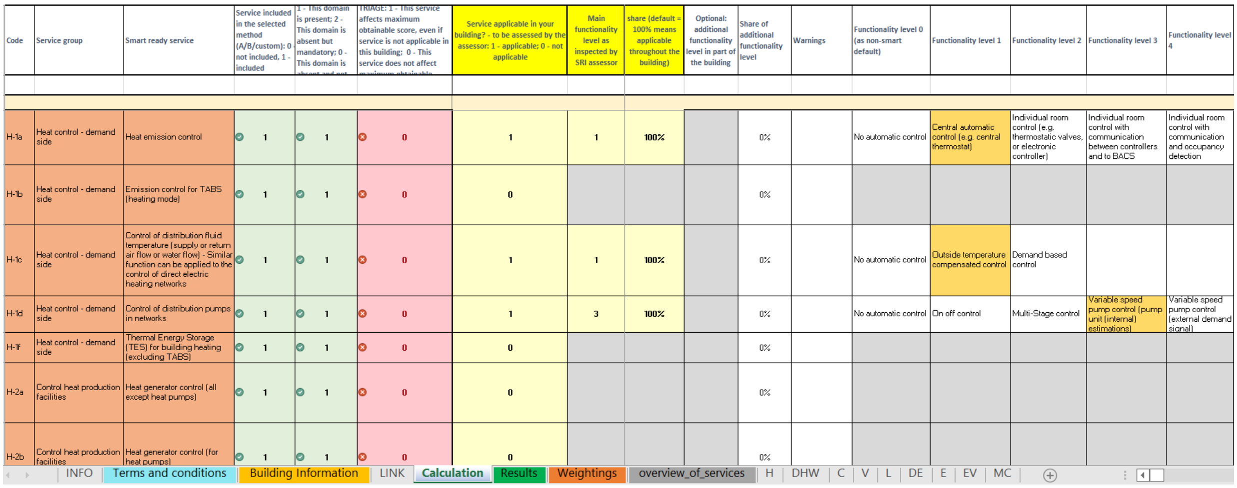
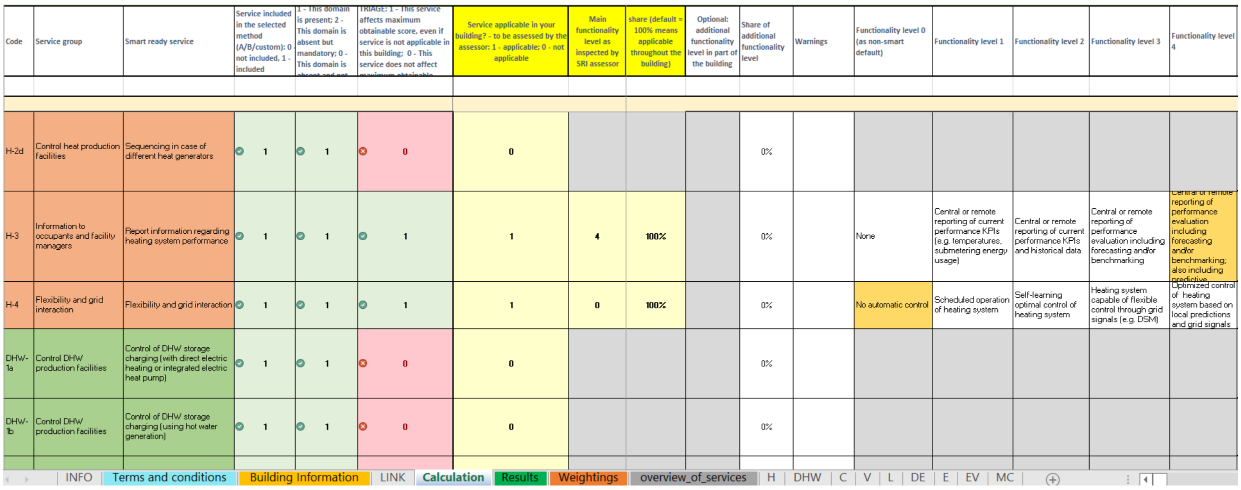
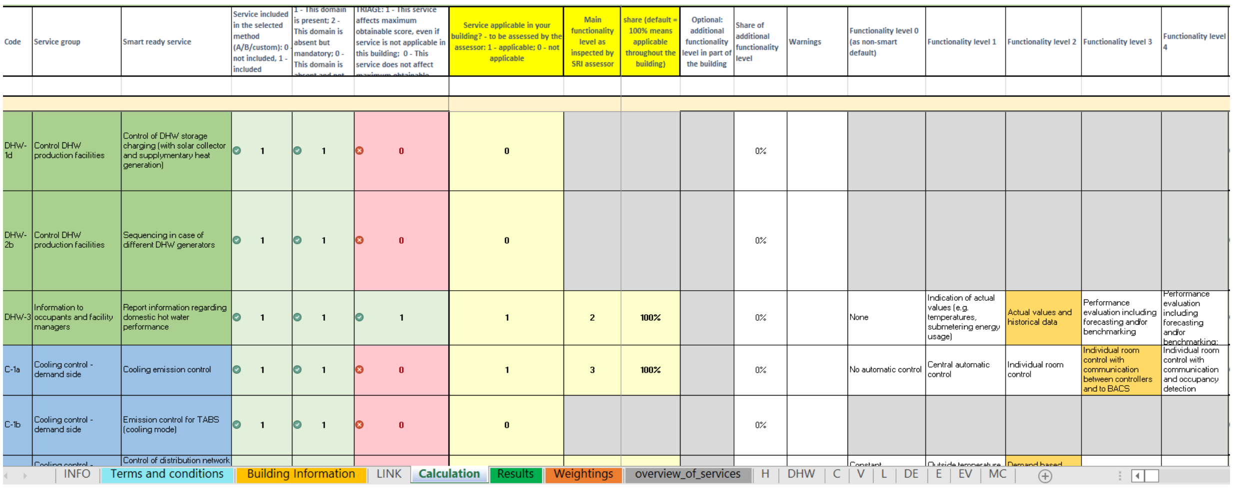
Appendix 1 - SRI Calculation sheet



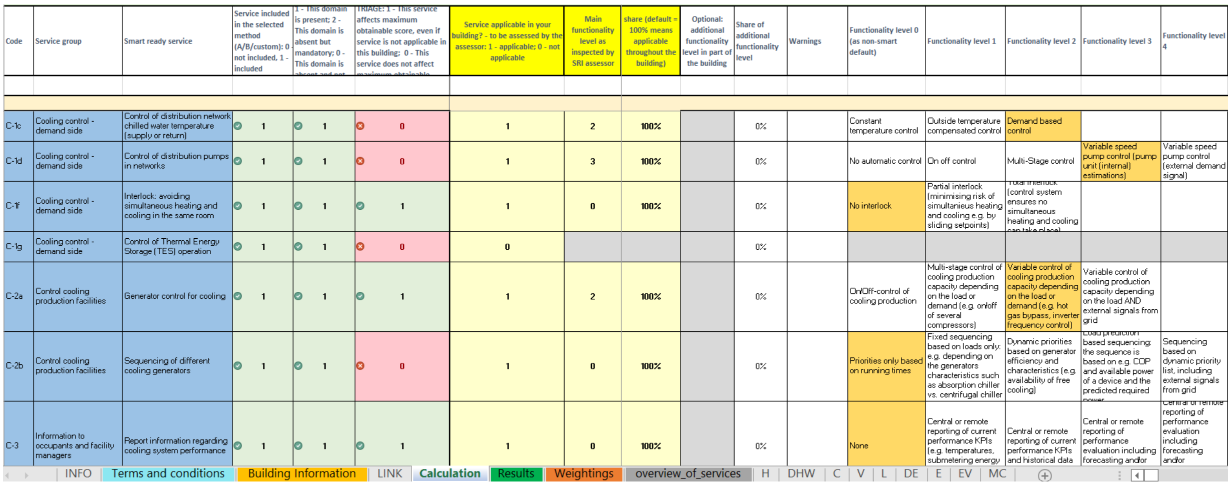
Code	Service group	Smart ready service	Service included in the selected method (A/B/custom): 0 - not included, 1 - included	1 - This domain is present; 2 - This domain is absent but mandatory; 0 - This domain is	TRIAGE: 1 - This service affects maximum obtainable score, even if service is not applicable in this building; 0 - This service does not affect	Service applicable in your building? - to be assessed by the assessor: 1 - applicable; 0 - not applicable	Main functionality level as inspected by SRI assessor	share (default = 100% means applicable throughout the building)	Optional: additional functionality level in part of the building	Share of additional functionality level	Warnings	Functionality level 0 (as non-smart default)	Functionality level 1	Functionality level 2	Functionality level 3	Functionality level 4
H-1a	Heat control - demand side	Heat emission control	✓ 1	✓ 1	⊗ 0	1	1	100%		0%		No automatic control	Central automatic control (e.g. central thermostat)	Individual room control (e.g. thermostatic valves, or electronic controller)	Individual room control with communication between controllers and to BACS	Individual room control with communication and occupancy detection
H-1b	Heat control - demand side	Emission control for TABS (heating mode)	✓ 1	✓ 1	⊗ 0	0				0%						
H-1c	Heat control - demand side	Control of distribution fluid temperature (supply or return air flow or water flow) - Similar function can be applied to the control of direct electric heating networks	✓ 1	✓ 1	⊗ 0	1	1	100%		0%		No automatic control	Outside temperature compensated control	Demand based control		
H-1d	Heat control - demand side	Control of distribution pumps in networks	✓ 1	✓ 1	⊗ 0	1	3	100%		0%		No automatic control	On off control	Multi-Stage control	Variable speed pump control (pump unit (internal) estimations)	Variable speed pump control (external demand signal)
H-1f	Heat control - demand side	Thermal Energy Storage (TES) for building heating (excluding TABS)	✓ 1	✓ 1	⊗ 0	0				0%						
H-2a	Control heat production facilities	Heat generator control (all except heat pumps)	✓ 1	✓ 1	⊗ 0	0				0%						
H-2b	Control heat production facilities	Heat generator control (for heat pumps)	✓ 1	✓ 1	⊗ 0	0				0%						



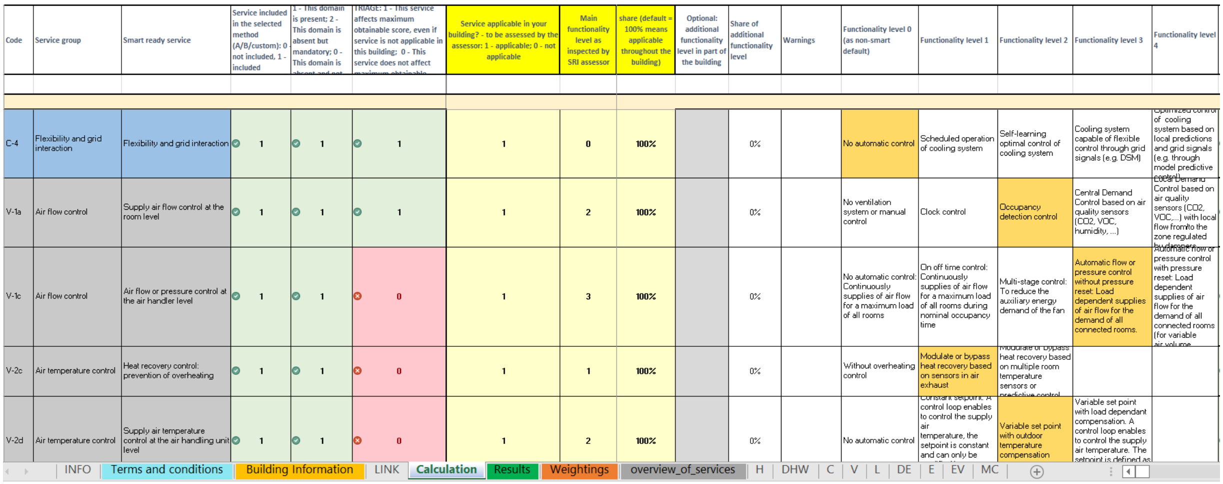
Code	Service group	Smart ready service	Service included in the selected method (A/B/custom): 0 - not included, 1 - included	1 - This domain is present; 2 - This domain is absent but mandatory; 0 - This domain is	TRIAGE: 1 - This service affects maximum obtainable score, even if service is not applicable in this building; 0 - This service does not affect	Service applicable in your building? - to be assessed by the assessor: 1 - applicable; 0 - not applicable	Main functionality level as inspected by SRI assessor	share (default = 100% means applicable throughout the building)	Optional: additional functionality level in part of the building	Share of additional functionality level	Warnings	Functionality level 0 (as non-smart default)	Functionality level 1	Functionality level 2	Functionality level 3	Functionality level 4
H-2d	Control heat production facilities	Sequencing in case of different heat generators	✓ 1	✓ 1	⊗ 0	0				0%						
H-3	Information to occupants and facility managers	Report information regarding heating system performance	✓ 1	✓ 1	✓ 1	1	4	100%		0%		None	Central or remote reporting of current performance KPIs (e.g. temperatures, submetering energy usage)	Central or remote reporting of current performance KPIs and historical data	Central or remote reporting of performance evaluation including forecasting and/or benchmarking	Central or remote reporting of performance evaluation including forecasting and/or benchmarking; also including predictive
H-4	Flexibility and grid interaction	Flexibility and grid interaction	✓ 1	✓ 1	✓ 1	1	0	100%		0%		No automatic control	Scheduled operation of heating system	Self-learning optimal control of heating system	Heating system capable of flexible control through grid signals (e.g. DSM)	Optimized control of heating system based on local predictions and grid signals
DHW-1a	Control DHW production facilities	Control of DHW storage charging (with direct electric heating or integrated electric heat pump)	✓ 1	✓ 1	⊗ 0	0				0%						
DHW-1b	Control DHW production facilities	Control of DHW storage charging (using hot water generation)	✓ 1	✓ 1	⊗ 0	0				0%						



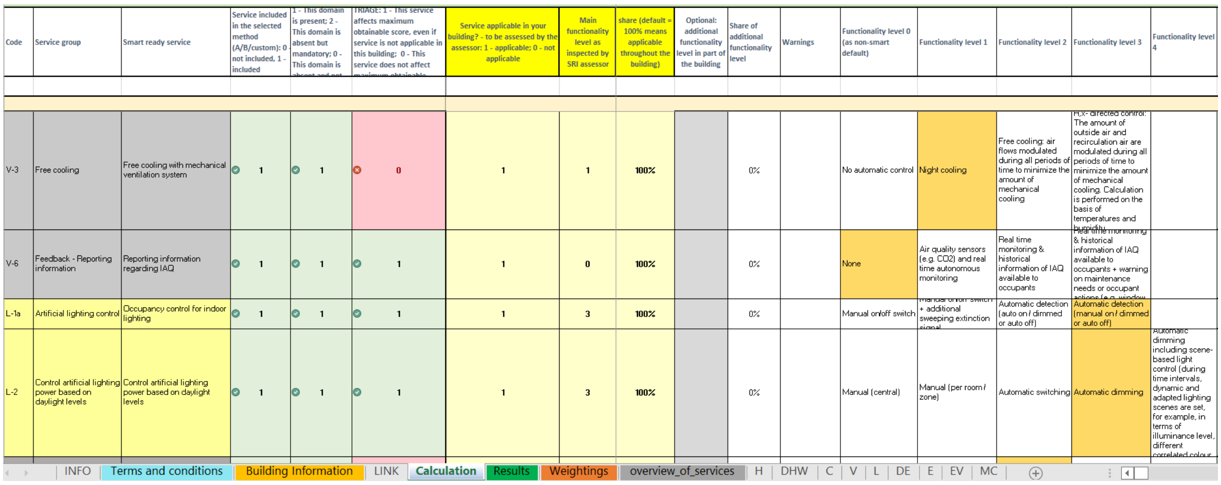
Code	Service group	Smart ready service	Service included in the selected method (A/B/custom): 0 - not included, 1 - included	1 - This domain is present; 2 - This domain is absent but mandatory; 0 - This domain is	TRIAGE: 1 - This service affects maximum obtainable score, even if service is not applicable in this building; 0 - This service does not affect	Service applicable in your building? - to be assessed by the assessor: 1 - applicable; 0 - not applicable	Main functionality level as inspected by SRI assessor	share (default = 100% means applicable throughout the building)	Optional: additional functionality level in part of the building	Share of additional functionality level	Warnings	Functionality level 0 (as non-smart default)	Functionality level 1	Functionality level 2	Functionality level 3	Functionality level 4
DHW-1d	Control DHW production facilities	Control of DHW storage charging (with solar collector and supplymentary heat generation)	✓ 1	✓ 1	⊗ 0	0				0%						
DHW-2b	Control DHW production facilities	Sequencing in case of different DHW generators	✓ 1	✓ 1	⊗ 0	0				0%						
DHW-3	Information to occupants and facility managers	Report information regarding domestic hot water performance	✓ 1	✓ 1	✓ 1	1	2	100%		0%		None	Indication of actual values (e.g. temperatures, submetering energy usage)	Actual values and historical data	Performance evaluation including forecasting and/or benchmarking	Performance evaluation including forecasting and/or benchmarking;
C-1a	Cooling control - demand side	Cooling emission control	✓ 1	✓ 1	⊗ 0	1	3	100%		0%		No automatic control	Central automatic control	Individual room control	Individual room control with communication between controllers and to BACS	Individual room control with communication and occupancy detection
C-1b	Cooling control - demand side	Emission control for TABS (cooling mode)	✓ 1	✓ 1	⊗ 0	0				0%						
	Cooling control -	Control of distribution network										Constant	Outside temperature	Demand based		



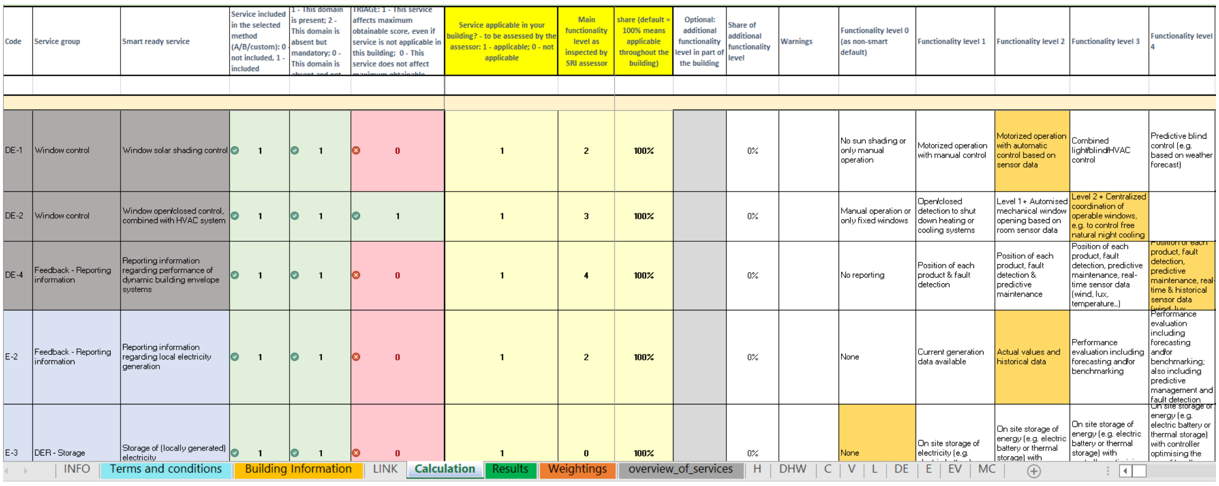
Code	Service group	Smart ready service	Service included in the selected method (A/B/custom): 0 - not included, 1 - included	1 - This domain is present; 2 - This domain is absent but mandatory; 0 - This domain is	TRIAGE: 1 - This service affects maximum obtainable score, even if service is not applicable in this building; 0 - This service does not affect	Service applicable in your building? - to be assessed by the assessor: 1 - applicable; 0 - not applicable	Main functionality level as inspected by SRI assessor	share (default = 100% means applicable throughout the building)	Optional: additional functionality level in part of the building	Share of additional functionality level	Warnings	Functionality level 0 (as non-smart default)	Functionality level 1	Functionality level 2	Functionality level 3	Functionality level 4
C-1c	Cooling control - demand side	Control of distribution network chilled water temperature (supply or return)	✓ 1	✓ 1	✗ 0	1	2	100%		0%		Constant temperature control	Outside temperature compensated control	Demand based control		
C-1d	Cooling control - demand side	Control of distribution pumps in networks	✓ 1	✓ 1	✗ 0	1	3	100%		0%		No automatic control	On off control	Multi-Stage control	Variable speed pump control (pump unit (internal) estimations)	Variable speed pump control (external demand signal)
C-1f	Cooling control - demand side	Interlock: avoiding simultaneous heating and cooling in the same room	✓ 1	✓ 1	✓ 1	1	0	100%		0%		No interlock	Partial interlock (minimising risk of simultanieus heating and cooling e.g. by sliding setpoints)	Total interlock (control system ensures no simultaneous heating and cooling can take place)		
C-1g	Cooling control - demand side	Control of Thermal Energy Storage (TES) operation	✓ 1	✓ 1	✗ 0	0				0%						
C-2a	Control cooling production facilities	Generator control for cooling	✓ 1	✓ 1	✓ 1	1	2	100%		0%		On/Off-control of cooling production	Multi-stage control of cooling production capacity depending on the load or demand (e.g. on/off of several compressors)	Variable control of cooling production capacity depending on the load or demand (e.g. hot gas bypass, inverter frequency control)	Variable control of cooling production capacity depending on the load AND external signals from grid	
C-2b	Control cooling production facilities	Sequencing of different cooling generators	✓ 1	✓ 1	✗ 0	1	0	100%		0%		Priorities only based on running times	Fixed sequencing based on loads only: e.g. depending on the generators characteristics such as absorption chiller vs. centrifugal chiller	Dynamic priorities based on generator efficiency and characteristics (e.g. availability of free cooling)	Load prediction based sequencing: the sequence is based on e.g. COP and available power of a device and the predicted required power	Sequencing based on dynamic priority list, including external signals from grid
C-3	Information to occupants and facility managers	Report information regarding cooling system performance	✓ 1	✓ 1	✓ 1	1	0	100%		0%		None	Central or remote reporting of current performance KPIs (e.g. temperatures, submetering energy	Central or remote reporting of current performance KPIs and historical data	Central or remote reporting of performance evaluation including forecasting and/or	Central or remote reporting of performance evaluation including forecasting and/or



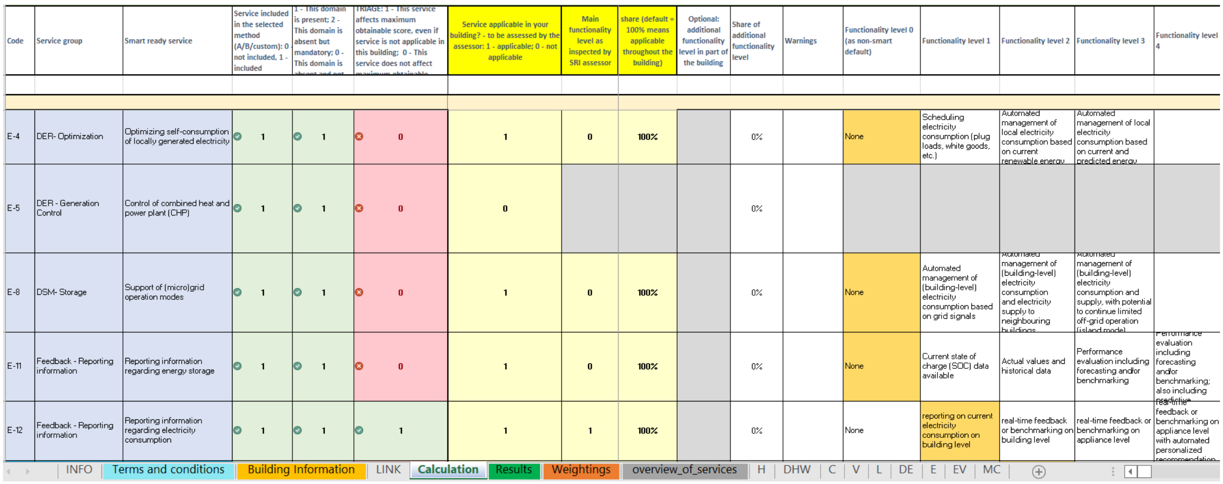
Code	Service group	Smart ready service	Service included in the selected method (A/B/custom): 0 - not included, 1 - included	1 - This domain is present; 2 - This domain is absent but mandatory; 0 - This domain is	TRIAGE: 1 - This service affects maximum obtainable score, even if service is not applicable in this building; 0 - This service does not affect	Service applicable in your building? - to be assessed by the assessor: 1 - applicable; 0 - not applicable	Main functionality level as inspected by SRI assessor	share (default = 100% means applicable throughout the building)	Optional: additional functionality level in part of the building	Share of additional functionality level	Warnings	Functionality level 0 (as non-smart default)	Functionality level 1	Functionality level 2	Functionality level 3	Functionality level 4
C-4	Flexibility and grid interaction	Flexibility and grid interaction	✓ 1	✓ 1	✓ 1	1	0	100%		0%		No automatic control	Scheduled operation of cooling system	Self-learning optimal control of cooling system	Cooling system capable of flexible control through grid signals (e.g. DSM)	Optimized control of cooling system based on local predictions and grid signals (e.g. through model predictive control)
V-1a	Air flow control	Supply air flow control at the room level	✓ 1	✓ 1	✓ 1	1	2	100%		0%		No ventilation system or manual control	Clock control	Occupancy detection control	Central Demand Control based on air quality sensors (CO2, VOC, humidity, ...)	Local Demand Control based on air quality sensors (CO2, VOC,...) with local flow from/to the zone regulated by dampers
V-1c	Air flow control	Air flow or pressure control at the air handler level	✓ 1	✓ 1	✗ 0	1	3	100%		0%		No automatic control: Continuously supplies of air flow for a maximum load of all rooms	On off time control: Continuously supplies of air flow for a maximum load of all rooms during nominal occupancy time	Multi-stage control: To reduce the auxiliary energy demand of the fan	Automatic flow or pressure control without pressure reset: Load dependent supplies of air flow for the demand of all connected rooms.	Automatic flow or pressure control with pressure reset: Load dependent supplies of air flow for the demand of all connected rooms (for variable air volume
V-2c	Air temperature control	Heat recovery control: prevention of overheating	✓ 1	✓ 1	✗ 0	1	1	100%		0%		Without overheating control	Modulate or bypass heat recovery based on sensors in air exhaust	Modulate or bypass heat recovery based on multiple room temperature sensors or predictive control		
V-2d	Air temperature control	Supply air temperature control at the air handling unit level	✓ 1	✓ 1	✗ 0	1	2	100%		0%		No automatic control	Constant setpoint: A control loop enables to control the supply air temperature, the setpoint is constant and can only be	Variable set point with outdoor temperature compensation	Variable set point with load dependant compensation. A control loop enables to control the supply air temperature. The setpoint is defined as	



Code	Service group	Smart ready service	Service included in the selected method (A/B/custom): 0 - not included, 1 - included	1 - This domain is present; 2 - This domain is absent but mandatory; 0 - This domain is	TRIAGE: 1 - This service affects maximum obtainable score, even if service is not applicable in this building; 0 - This service does not affect	Service applicable in your building? - to be assessed by the assessor: 1 - applicable; 0 - not applicable	Main functionality level as inspected by SRI assessor	share (default = 100% means applicable throughout the building)	Optional: additional functionality level in part of the building	Share of additional functionality level	Warnings	Functionality level 0 (as non-smart default)	Functionality level 1	Functionality level 2	Functionality level 3	Functionality level 4
V-3	Free cooling	Free cooling with mechanical ventilation system	✓ 1	✓ 1	✗ 0	1	1	100%		0%		No automatic control	Night cooling	Free cooling: air flows modulated during all periods of time to minimize the amount of mechanical cooling	H,x- directed control: The amount of outside air and recirculation air are modulated during all periods of time to minimize the amount of mechanical cooling. Calculation is performed on the basis of temperatures and humidity	
V-6	Feedback - Reporting information	Reporting information regarding IAQ	✓ 1	✓ 1	✓ 1	1	0	100%		0%		None	Air quality sensors (e.g. CO2) and real time autonomous monitoring	Real time monitoring & historical information of IAQ available to occupants	Real time monitoring & historical information of IAQ available to occupants + warning on maintenance needs or occupant actions (e.g. window	
L-1a	Artificial lighting control	Occupancy control for indoor lighting	✓ 1	✓ 1	✓ 1	1	3	100%		0%		Manual on/off switch	Manual on/off switch + additional sweeping extinction signal	Automatic detection (auto on / dimmed or auto off)	Automatic detection (manual on / dimmed or auto off)	
L-2	Control artificial lighting power based on daylight levels	Control artificial lighting power based on daylight levels	✓ 1	✓ 1	✓ 1	1	3	100%		0%		Manual (central)	Manual (per room / zone)	Automatic switching	Automatic dimming	Automatic dimming including scene-based light control (during time intervals, dynamic and adapted lighting scenes are set, for example, in terms of illuminance level, different correlated colour



Code	Service group	Smart ready service	Service included in the selected method (A/B/custom): 0 - not included, 1 - included	1 - This domain is present; 2 - This domain is absent but mandatory; 0 - This domain is	TRIAGE: 1 - This service affects maximum obtainable score, even if service is not applicable in this building; 0 - This service does not affect	Service applicable in your building? - to be assessed by the assessor: 1 - applicable; 0 - not applicable	Main functionality level as inspected by SRI assessor	share (default = 100% means applicable throughout the building)	Optional: additional functionality level in part of the building	Share of additional functionality level	Warnings	Functionality level 0 (as non-smart default)	Functionality level 1	Functionality level 2	Functionality level 3	Functionality level 4
DE-1	Window control	Window solar shading control	✓ 1	✓ 1	✗ 0	1	2	100%		0%		No sun shading or only manual operation	Motorized operation with manual control	Motorized operation with automatic control based on sensor data	Combined light/blind/HVAC control	Predictive blind control (e.g. based on weather forecast)
DE-2	Window control	Window open/closed control, combined with HVAC system	✓ 1	✓ 1	✓ 1	1	3	100%		0%		Manual operation or only fixed windows	Open/closed detection to shut down heating or cooling systems	Level 1 + Automised mechanical window opening based on room sensor data	Level 2 + Centralized coordination of operable windows, e.g. to control free natural night cooling	
DE-4	Feedback - Reporting information	Reporting information regarding performance of dynamic building envelope systems	✓ 1	✓ 1	✗ 0	1	4	100%		0%		No reporting	Position of each product & fault detection	Position of each product, fault detection & predictive maintenance	Position of each product, fault detection, predictive maintenance, real-time sensor data (wind, lux, temperature...)	Position of each product, fault detection, predictive maintenance, real-time & historical sensor data (wind, lux,
E-2	Feedback - Reporting information	Reporting information regarding local electricity generation	✓ 1	✓ 1	✗ 0	1	2	100%		0%		None	Current generation data available	Actual values and historical data	Performance evaluation including forecasting and/or benchmarking	Performance evaluation including forecasting and/or benchmarking; also including predictive management and fault detection
E-3	DER - Storage	Storage of (locally generated) electricity	✓ 1	✓ 1	✗ 0	1	0	100%		0%		None	On site storage of electricity (e.g.	On site storage of energy (e.g. electric battery or thermal storage) with	On site storage of energy (e.g. electric battery or thermal storage) with	On site storage of energy (e.g. electric battery or thermal storage) with controller optimising the



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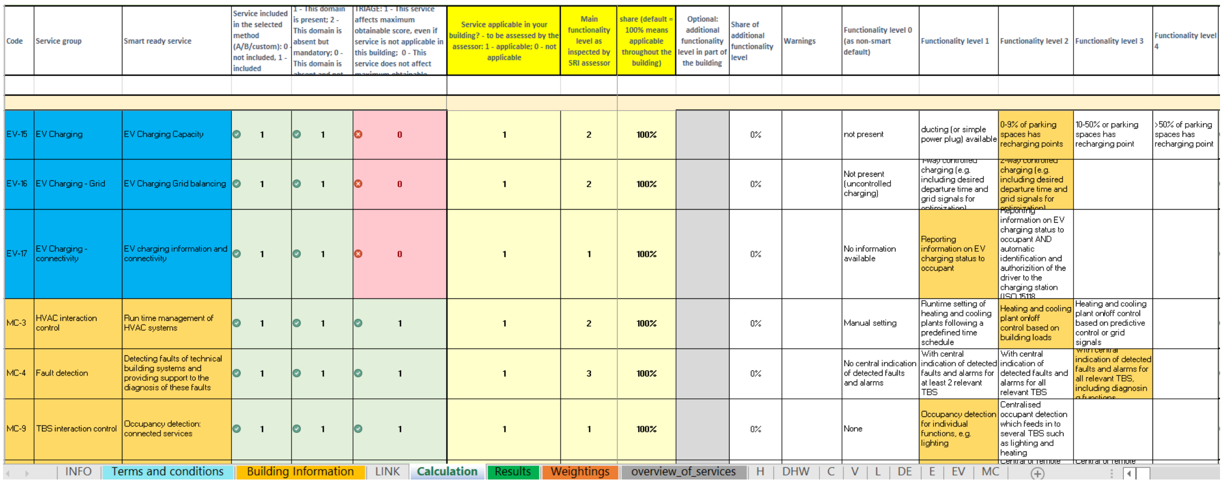
E-4	DER- Optimization	Optimizing self-consumption of locally generated electricity	✓ 1	✓ 1	✗ 0	1	0	100%		0%		None	Scheduling electricity consumption (plug loads, white goods, etc.)	Automated management of local electricity consumption based on current renewable energy	Automated management of local electricity consumption based on current and predicted energy	
E-5	DER - Generation Control	Control of combined heat and power plant (CHP)	✓ 1	✓ 1	✗ 0	0				0%						
E-8	DSM- Storage	Support of (micro)grid operation modes	✓ 1	✓ 1	✗ 0	1	0	100%		0%		None	Automated management of (building-level) electricity consumption based on grid signals	Automated management of (building-level) electricity consumption and electricity supply to neighbouring buildings	Automated management of (building-level) electricity consumption and supply, with potential to continue limited off-grid operation (island mode)	
E-11	Feedback - Reporting information	Reporting information regarding energy storage	✓ 1	✓ 1	✗ 0	1	0	100%		0%		None	Current state of charge (SOC) data available	Actual values and historical data	Performance evaluation including forecasting and/or benchmarking	Performance evaluation including forecasting and/or benchmarking; also including predictive
E-12	Feedback - Reporting information	Reporting information regarding electricity consumption	✓ 1	✓ 1	✓ 1	1	1	100%		0%		None	reporting on current electricity consumption on building level	real-time feedback or benchmarking on building level	real-time feedback or benchmarking on appliance level	real-time feedback or benchmarking on appliance level with automated personalized recommendation



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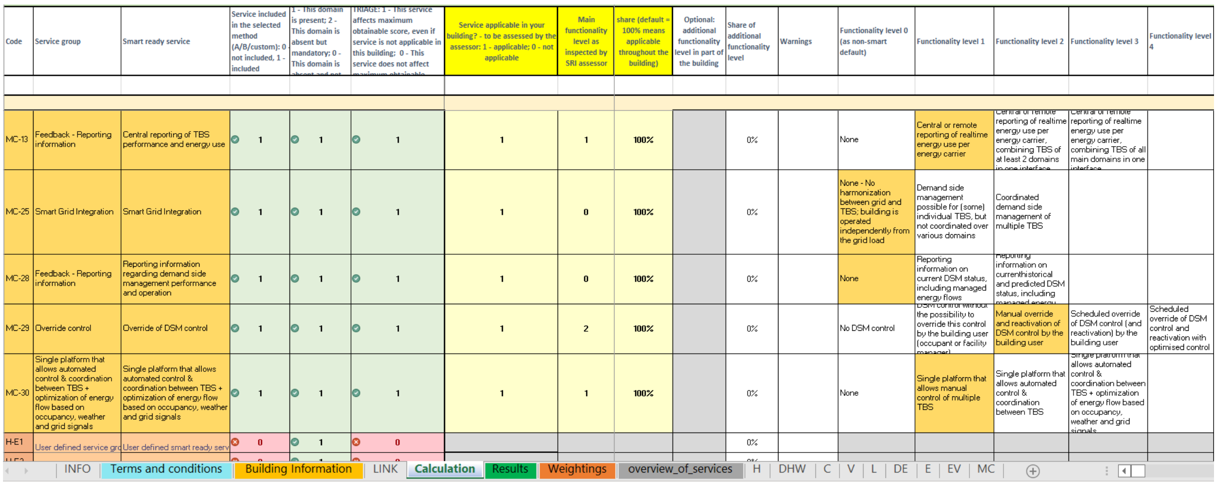
EV-15	EV Charging	EV Charging Capacity	✓ 1	✓ 1	✗ 0	1	2	100%		0%		not present	ducting (or simple power plug) available	0-9% of parking spaces has recharging points	10-50% or parking spaces has recharging point	>50% of parking spaces has recharging point
EV-16	EV Charging - Grid	EV Charging Grid balancing	✓ 1	✓ 1	✗ 0	1	2	100%		0%		Not present (uncontrolled charging)	1-way controlled charging (e.g. including desired departure time and grid signals for optimization)	2-way controlled charging (e.g. including desired departure time and grid signals for optimization)		
EV-17	EV Charging - connectivity	EV charging information and connectivity	✓ 1	✓ 1	✗ 0	1	1	100%		0%		No information available	Reporting information on EV charging status to occupant	Reporting information on EV charging status to occupant AND automatic identification and authorizition of the driver to the charging station (ISO 15118		
MC-3	HVAC interaction control	Run time management of HVAC systems	✓ 1	✓ 1	✓ 1	1	2	100%		0%		Manual setting	Runtime setting of heating and cooling plants following a predefined time schedule	Heating and cooling plant on/off control based on building loads	Heating and cooling plant on/off control based on predictive control or grid signals	
MC-4	Fault detection	Detecting faults of technical building systems and providing support to the diagnosis of these faults	✓ 1	✓ 1	✓ 1	1	3	100%		0%		No central indication of detected faults and alarms	With central indication of detected faults and alarms for at least 2 relevant TBS	With central indication of detected faults and alarms for all relevant TBS	With central indication of detected faults and alarms for all relevant TBS, including diagnosing functions	
MC-9	TBS interaction control	Occupancy detection: connected services	✓ 1	✓ 1	✓ 1	1	1	100%		0%		None	Occupancy detection for individual functions, e.g. lighting	Centralised occupant detection which feeds in to several TBS such as lighting and heating		



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MC-13	Feedback - Reporting information	Central reporting of TBS performance and energy use	✓ 1	✓ 1	✓ 1	1	1	100%		0%		None	Central or remote reporting of realtime energy use per energy carrier	Central or remote reporting of realtime energy use per energy carrier, combining TBS of at least 2 domains in one interface	Central or remote reporting of realtime energy use per energy carrier, combining TBS of all main domains in one interface	
MC-25	Smart Grid Integration	Smart Grid Integration	✓ 1	✓ 1	✓ 1	1	0	100%		0%		None - No harmonization between grid and TBS; building is operated independently from the grid load	Demand side management possible for (some) individual TBS, but not coordinated over various domains	Coordinated demand side management of multiple TBS		
MC-28	Feedback - Reporting information	Reporting information regarding demand side management performance and operation	✓ 1	✓ 1	✓ 1	1	0	100%		0%		None	Reporting information on current DSM status, including managed energy flows	Reporting information on currenthistorical and predicted DSM status, including managed energy		
MC-29	Override control	Override of DSM control	✓ 1	✓ 1	✓ 1	1	2	100%		0%		No DSM control	DSM control without the possibility to override this control by the building user (occupant or facility manager)	Manual override and reactivation of DSM control by the building user	Scheduled override of DSM control (and reactivation) by the building user	Scheduled override of DSM control and reactivation with optimised control
MC-30	Single platform that allows automated control & coordination between TBS + optimization of energy flow based on occupancy, weather and grid signals	Single platform that allows automated control & coordination between TBS + optimization of energy flow based on occupancy, weather and grid signals	✓ 1	✓ 1	✓ 1	1	1	100%		0%		None	Single platform that allows manual control of multiple TBS	Single platform that allows automated control & coordination between TBS	Single platform that allows automated control & coordination between TBS + optimization of energy flow based on occupancy, weather and grid signals	
H-E1	User defined service gro	User defined smart ready serv	✗ 0	✓ 1	✗ 0					0%						