E2B2 - forskning och innovation för energieffektivt byggande och boende

Active load control in housing association

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E2B2

Förord

E2B2s vision är en resurs- och energieffektiv byggd miljö.

Bebyggelsesektorn svarar för cirka en tredjedel av Sveriges totala energianvändning och en effektivare energianvändning är en viktig del av utvecklingen av energisystemet. Hållbarhet, effektivitet och robusthet i bebyggelsen behöver stärkas och utvecklas. Lösningarna behöver samspela för att fungera och utnyttjas. Forskning, utveckling, innovation och kommersialisering spelar en avgörande roll.

I E2B2 arbetar forskare och andra aktörer tillsammans för att utveckla samhällets byggande och boende och effektivisera energianvändningen. Syftet med E2B2 är att ta fram ny kunskap, teknik, tjänster och metoder som bidrar till en hållbar energi- och resursanvändning i bebyggelsen.

E2B2 är ett forsknings- och innovationsprogram från Energimyndigheten där IQ Samhällsbyggnad är koordinator. Programmet startade 2013 och en andra programperiod pågår mellan 2018 och 2024. Projektet som beskrivs i den här rapporten har genomförts i programmet med hjälp av statligt stöd från Energimyndigheten.

Stockholm, 15 mars 2024

Sammanfattning

Effekt- och kapacitetsbrist är två begrepp som används flitigt i Sverige och som kan komma att öka med en större andel väderberoende elproduktion i elsystemet. Detta bedöms leda till ett ökat behov av flexibilitet hos slutanvändarna för att balansera variationer från väderberoende källor som vind- och solkraft, vilket kan åtgärdas genom att utnyttja flexibilitet hos slutanvändaren genom laststyrning. Målet med projektet var att implementera och utvärdera olika styrstrategier för laststyrning i en bostadsrättsförening. Analysen baseras på uppmätt data för laster som bedömdes kunna bidra till flexibilitet från vilka RISE hade tillgång till energimätning. Det är den delen av den totala förbrukningen som skulle kunna kontrolleras. De huvudsakliga kontrollerbara resurserna som använts för analysen var tre radiatorkedjor på cirka 1 kW vardera, ett 15 kWh/6kW batteri och 12x3.6 kW elbilsladdare. Tre olika styrstrategier implementerades, C1 – Timer, C2 – Effektvakt och C3 – Realtidsstyrning. Dessa utvärderades både på energi- och effekttariffer utifrån de nya energiprofilerna baserat på styrstrategierna. Resultatet visade att när det gäller effekt från elnätet stod elbilsladdarna för den högsta procentuella delen av lasten, därför är det viktigt att fokusera på optimal laddning/schemaläggning för att minska toppbelastningen. En hybrid styrning med elbilsladdarna och batteriet hade störst besparingspotential. Laststyrningen resulterade i följande spann för årliga besparingar C1: 630–2400 SEK, C2: 550–1500 SEK och C3: 3100–16000 SEK. Detta motsvarar procentuella besparingar på 1.2-2.3%, 1.1-2.6% och 5.6-15% jämfört med den beräknade grundlasten. Nuvarande effekttariffer gav en mindre ökning av besparingar jämfört med energibaserade tariffer. Dessa skillnader kan komma att förstärkas, vilket kan leda till större besparingar med mer strikta tariffer. Även om aktiv laststyrning ger många fördelar, är det viktigt att erkänna de utmaningar och begränsningar som är förknippade med implementeringen. En utmaning ligger i behovet av robust kommunikationsinfrastruktur och mätsystem för att möjliggöra kontroll och övervakning i realtid. Aktiv laststyrning har potential att förändra energiförbrukningsmönster, minska kostnaderna och främja hållbar energiutveckling vilket understryker vikten av fortsatt forskning, innovation och samarbete för dess omfattande implementering och integration i det framtida energisystemet.

Flexibilitet, flerfamiljshus, batteri, laststyrning, elbilsladdare, tariffer

Summary

Power and capacity shortage are two concepts that are talked about frequently in Sweden and which may increase with a greater share of weather-dependent electricity production in the electricity system. This is judged to lead to an increased need for flexibility on the part of end users to balance variations from weather-dependent sources such as wind and solar power, which can be addressed by utilizing flexibility on the end-user side by load control. The objective of the project was to implement and assess different control strategies for load management in a housing association. The analysis is based on measured data for loads that were judged to be able to contribute to flexibility from appliances for which RISE had access to energy metering. It is the part of the total consumption which could be controlled. The main controllable resources utilized in the analysis were three radiator chains around 1 kW each, a 15 kWh/6kW battery and 12x3.6 kW EV chargers. Three different control strategies were implemented, C1 – Timer, C2 – Power guard and C3 – Real time control. These were evaluated on both energy and power tariffs based on the new energy profiles from the control dispatches. The result showed that in terms of power drawn from the grid, the EVs had the highest percentage charge of the load, therefore focusing on optimal charging/ scheduling is important to reduce the peak load. A hybrid control strategy with the electric car chargers and the battery had the greatest savings potential. The load management resulted in the following ranges for annual savings C1: 630–2400 SEK, C2: 550–1500 SEK, and C3: 3100–16000 SEK, corresponding to percentage savings of 1.2-2.3%, 1.1-2.6%, and 5.6-15% compared to the calculated base load. Current power tariffs offered a slight increase in savings as compared to energy-based tariffs. These differences may become more pronounced, offering higher savings with a stricter tariff structure. While active load management offers numerous benefits, it is essential to acknowledge the challenges and limitations associated with its implementation. One challenge lies in the need for robust communication infrastructure and smart metering systems to enable real-time control and monitoring. Active load management has a potential to shift energy consumption patterns, mitigate costs, and foster sustainable energy practices, underscoring the importance of continued research, innovation, and collaboration for its widespread implementation and integration into the future energy system.

Flexibility, multifamily housing, battery, load control, EV chargers, tariffs

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1 Introduction

1.1 Background

Power and capacity shortage are two concepts that are being talked about frequently in Sweden and which may increase with a greater share of renewable electricity production in the electricity system [1]. This is judged to lead to an increased need for flexibility on the part of end users to balance variations from weather-dependent sources such as wind and solar power [2]. Electric heating loads in residential properties have potential for flexibility, both in terms of energy quantity and load-shifting capabilities. Through load control, heating loads can be coordinated with other resources, such as electric vehicle chargers, batteries, and solar power generation, many of which have seen a steady rate of increase at the consumer side [3,4]. This coordination can be used to reduce maximum power draw and/or provide system services to regional and national grid owners. Power tariffs are one way to influence consumer power usage, but they can also lead to increased costs for consumers. In the Creating Automotive Renewal (CAR) project [5] RISE has looked at the transition to an electrified mobility system with a demonstration facility for a smart charging infrastructure that includes solar cells and batteries at a BRF in Lund, Solbyn, the project site. The communication layout is illustrated in Figure 1 below, the site is described in detail in Appendix A.

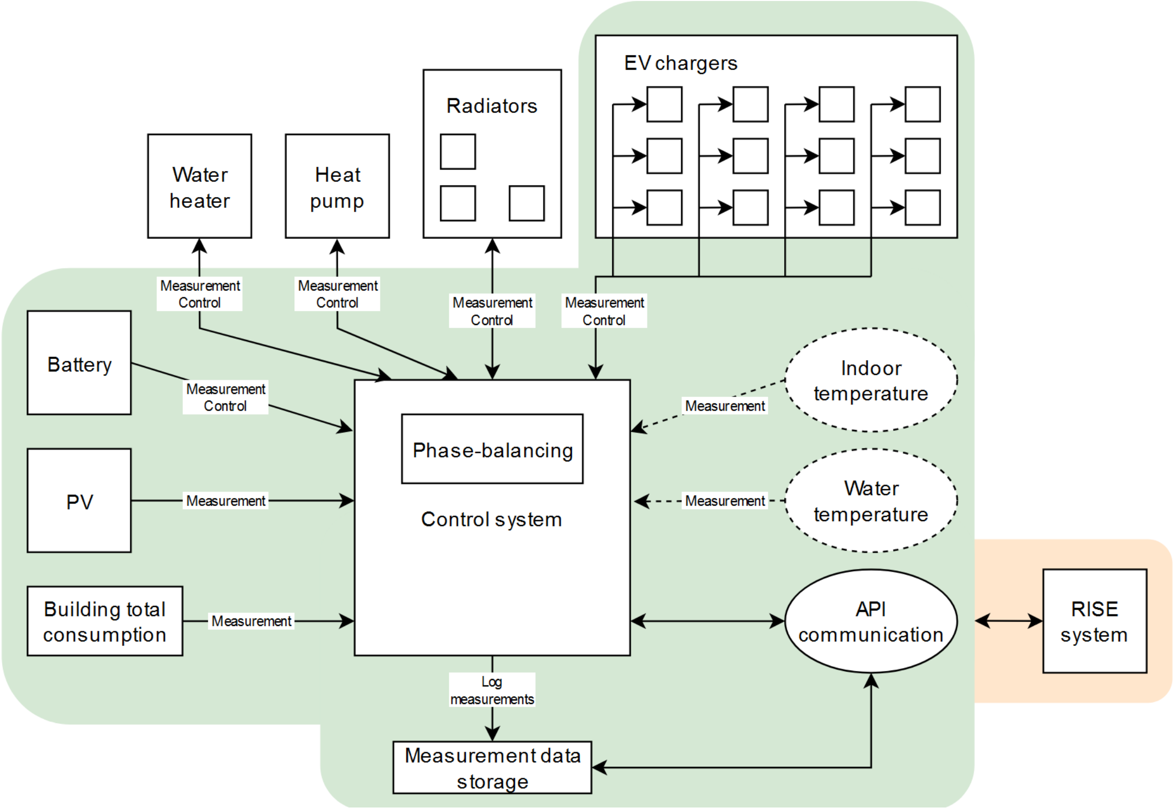


Figure 1: Project site energy equipment and measuring devices.

1.2 Aim

The aim of the project was to implement and assess different control approaches for load management in a housing association with electric heating systems, including radiators, heat pumps, and charging infrastructure for electric vehicles. The project had three main aims:

1. Assess various controllable resources, their coordination, and their synergy to effectively minimize electricity demand at residential property level and maximize the self-consumption of solar production.
2. Evaluate different control strategies: timer, power monitoring, and real-time control focusing on residential properties.
3. Develop a tool to evaluate the energy consumption of residential properties for cost savings.

1.3 Scope and limitations

The conclusions from the project are mainly based on the housing association in the project site, however generalized implications of results are discussed.

In the project, the coordination of direct load control encountered challenges leading to the control strategies not being implemented at the physical location. These related to the deliverance, procurement and ongoing management of the hardware component required for the control system and the data collection.

The project team worked to address these issues and leverage the simulation implementation to compare control strategies in a virtual environment. This is further addressed in the discussion section of the report in Chapter 4 and the installations and timeline in Appendix A.

2 Method

2.1 Load and flexible resources

This chapter focuses on the characterization of flexible resources and provides an overview of the methodology applied to calculate the baseline energy consumption for comparison purposes. The section highlights the energy appliances used in the project and the resource description. Additionally, it addresses the gaps in the recorded data due to communication issues from the measurement devices encountered during information gathering and measurements.

To compare the profitability of different solutions, it was necessary to establish a baseline energy consumption profile for reference. The baseline profile serves as a benchmark against which the effectiveness of various control solutions could be evaluated. The methodology applied in calculating the baseline profile involved analyzing the energy consumption of different appliances within the facility. The resource description outlines the key parameters of the energy appliances, average hourly demand, the peak power, and ramp rate for understanding the capabilities and characteristics of the flexible resources. Table 1 provides an overview of the measurements. In this report, the radiators, hot water heater, heat pump and EV chargers are together referred to as flexible loads.

Table 1: Resource description.

Measurement	**Average hourly energy demand (kWh)**	**Peak power (kW)**	**Max ramp-rate (kW / minute)**
Radiators 1-3	0.10 – 0.51	0.71 – 2.73	1.51
Water heater	0.37	5.99	4.19
Heat pump	0.19	0.77	0.54
Solar cell strings 1-2	-4.7	-36.9	-26.8
Battery	Capacity: 15 kWh	-5.0, 5.0	-4.8, 4.5
EV chargers 1-6	2.71	3.6x12	10.0

The load profiles recorded for each of the flexible resource listed in Table 1 are presented in Figure 2 below. Note that the EV profile is an aggregate profile corresponding to the sum of the charge points on site. The battery and the solar profiles are not shown in this figure. The measurements were carried out between 2022-06-23 and 2023-06-22 for a full year of data.

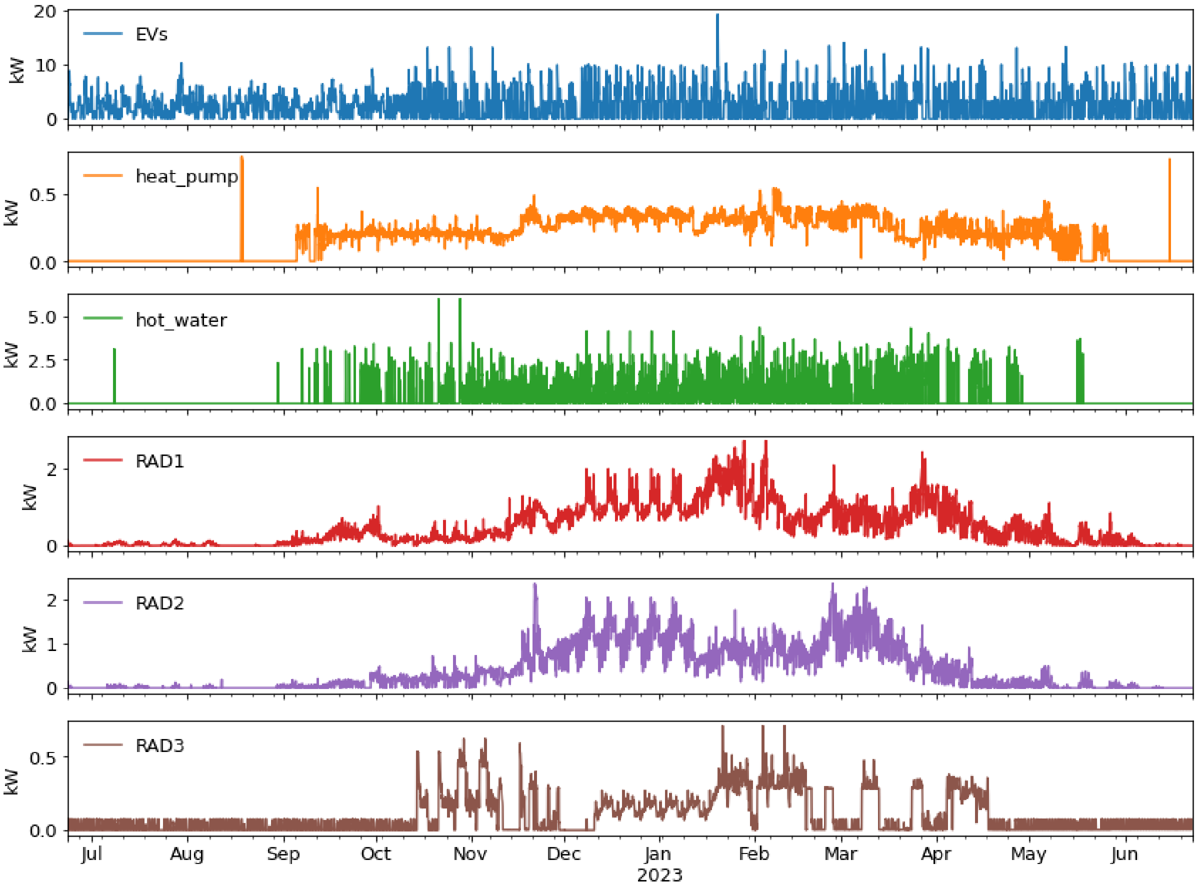


Figure 2: Hourly load profiles for the flexible resources at the BRF between June 2022 and June 2023.

During the data collection process, it became evident that certain time intervals contained gaps in the recorded data. These gaps were attributed to communication issues that occurred during the information gathering phase. It is important to note that these gaps are consistent across the recorded time series for all appliances. The data presented in Figure 2 are presented as cleaned time-series, wherein the data gaps have been filled. Appendix B provides details on the methods employed to compensate for the missing values and ensure the accuracy of the measurements.

For a more comprehensive understanding of the technical issues encountered at the site and in recording measurement data refer to Appendix A of this report.

2.2 Control strategies

This chapter focuses on the control strategies employed in the project to evaluate their effectiveness in reducing power peaks and achieving cost reductions. The three control strategies considered in this project were time-based control, demand limit-based control, and real-time control using a battery system. These strategies provide different approaches to managing energy consumption in achieving cost reductions. Table 2 provides a summary of the control strategies and their respective descriptions.

Table 2: Control strategies description.

Control Strategy	**Function**	**Input**	**Output**
Time based	Timed on/off applied to heat loads.	Time	On/off for each appliance
Demand limit based	Power limit based on a defined power threshold level	Demand limit Battery state-of-charge	Battery control dispatch
Real time battery dispatch	Optimised battery operation to maximise self-consumption.	Battery state-of-charge	Battery control dispatch

The implementation of these control strategies offers different advantages in terms of energy management and cost reduction. Time-based control provides flexibility in scheduling appliance operations, allowing for reduced energy consumption throughout the year. Demand limit-based control ensures that the power usage remains within defined limits, avoiding unnecessary energy expenditures. Real-time control using battery systems optimizes energy usage, enabling the household to leverage cost-effective energy sources and minimize overall energy costs. The three control strategies considered in this project—time-based control, demand limit-based control, and real-time control using battery systems—offer distinct approaches to manage flexible resources.

2.2.1 Battery dispatch profiles

The battery dispatch control strategy calculates the optimal power flow (OPF) to evaluate its profile. OPF is a mathematical framework used extensively within the power industry to evaluate how generating units should be allocated to meet electricity demand at the lowest possible cost given the technical limitations of the system. A simulation framework of the property at Solbyn was therefore constructed to fit within this framework.

Specifically, OFP functionality is available through numerous commercial and open-source software applications. As part of this project, the pyPSA module [6] was used together with the GLPK solver owing to their open-source and easy to use nature, which offer several advantages. Firstly, open source OPF provides flexibility for customization, enabling tailored adjustments to account for the unique characteristics of the Solbyn multi-dwelling property, such as diverse energy demands and renewable generation patterns. Secondly, open source OPF encourages cost-effectiveness by eliminating the need for expensive proprietary software licenses, making it scalable for various projects and stakeholders within the region's energy sector.

2.3 Electricity tariffs

The economic evaluation is important in assessing the effectiveness and impact of the control strategies. This chapter focuses on evaluating the controls strategies of the project, in relation to electricity tariffs, grid fees and purchased electricity. By considering different electricity tariffs the aim is to analyze their influence on households' load profiles, energy bills, and overall energy consumption.

Electricity network companies are responsible for maintaining and operating the electrical grid. The costs associated with grid maintenance and operation are passed on to customers through network charges or grid fees. To compare network charges between different companies, Energimarknadsinspektionen (Ei) collects and publishes annual statistics on electricity network charges. In Sweden, the grid fee consists of a fixed part, known as the subscription fee, and a variable part, known as the electricity transfer fee. The breakdown of these fees varies based on factors such as fuse size or subscribed power. Analyzing network charges and grid fees allows for comparisons between companies and regional electricity providers, providing insights into the financial aspects of grid services. To evaluate the impact of electricity tariffs and grid fees, data from Ei is utilized [7]. For the purchased electricity the average cost of electricity in 2020-2022 [8], including subscription fees, transfer fees, and taxes [9], is considered. Electricity prices before 2020 are not considered since the year marked a price low [10]. The grid fee calculation involves variables such as energy consumption, governmental fees, fixed fees, VAT (*"moms"* in Sweden), and taxes. Additionally, the purchased power is calculated based on monthly energy consumption and the average monthly spot price in the price area. The grid fee and purchased power are calculated from:

$$C_{grid} = \left(C_{var} * \sum E_{annual} + C_{gov} + C_{fixed} + C_{tax} * \sum E_{annual}\right) * C_{VAT}$$

$$C_{purchased} = \sum_{i=1}^{12}(E_i * C_i)$$

$$C_{total} = C_{grid} + C_{purchased}$$

Table 3: Electricity tariff variables description.

Variable	C_var	C_gov	C_fixed	C_tax	C_VAT	E_annual	E_(1-12)	C_(1-12)
Description	Variable fee	Goverment fee	Fixed fee	Tax	VAT	Annual load	Monthly load	Monthly spot price
Unit	SEK/kWh	SEK/year	SEK/year	SEK/kWh	%	kWh	kWh	SEK/kWh

By applying this framework, the reduction in energy consumption can be analyzed. The analysis includes comparing electricity bills, grid fees and purchased electricity for different control strategies. It allows for understanding the cost implications of electricity consumption patterns. The findings provide insights into potential cost reduction, the effectiveness of different tariffs, and the variations in grid fees between electricity network companies and regions.

2.4 Cost reduction tool

Multi-family housings are often oversubscribed for their electricity fuse sizing [11]. A method is presented to describe how effectively the household subscription is used.

1. Calculate max(annual load) / (fuse size * 400 * sqrt(3))
2. Look-up table of fuse sizes based on peak consumption and annual energy.
3. If the subscription cannot be changed, check how much in kW/kWh is required.
4. Based on current subscription estimate savings for a flexible load profile.
5. Optional: If the hourly load contains a familiar load pattern, e.g., EV charging it can be accounted for to see the effect of rescheduling. An example is presented in Appendix D based on average Swedish driving annually [12], range and battery sizing [13].

The proposed method for evaluating if a household is overpaying for their electricity involves a series of steps to determine the appropriateness of the household's energy subscription. This method is based on calculating the household's annual energy consumption, peak power demand, and comparing these values to the size of the household's fuse. The following is a detailed description of each step of the method:

1. Determine the household's annual energy consumption in kilowatt-hours (kWh), based on available data such as monthly utility bills. This step involves collecting data on the household's energy usage over the course of a year, typically by analysing monthly utility bills or other energy usage data. The total energy consumption is calculated in kilowatt-hours (kWh), which is a standard unit of energy used by energy providers.
2. Calculate the household's peak power demand in kilowatts (kWh/h), based on the maximum energy usage observed during any given hour. This step involves identifying the hour during which the household used the most energy and calculating the maximum energy usage during that hour in kilowatt-hours (kWh) to obtain the peak power demand in kilowatts (kW).
3. Compare the household's peak power demand and annual energy consumption to their fuse size and determine if it is appropriately matched to the household's energy usage. This step involves comparing the calculated peak power demand in kilowatts (kW) and annual energy (kWh) to the size of the household's fuse. If the peak power demand is lower than the size of the fuse and the annual energy consumption is low, then the household's subscription may be adjusted to save money on the electricity bill.

Overall, the proposed method provides a straightforward and quantitative approach for evaluating the appropriateness of a household's energy subscription. By calculating the household's annual energy consumption, peak power demand, and comparing these values to the size of the household's fuse, the method can help households to identify potential issues with their energy subscriptions and avoid overpaying for their electricity.

3 Results

3.1 Baseload and flexible resources

To compare the profitability of different control strategies, it was necessary to establish baseline energy consumption profiles as a reference.

The baseload profile, in orange on Figure 3 is from Solbyn's account on the Skånska Energi web portal and represents the energy consumption of the BRF's common facilities. The blue line in Figure 3 highlights the flexible load recorded from the flexible resources from which RISE had access to energy meters. It is the component of the baseload which could be controlled. This flexible load profile serves as a benchmark against which the effectiveness of various control strategies is evaluated.

The data gaps within the aggregate flexible load have been filled from the trend of baseload profile, using a methodology described in Appendix B. The characteristics of the baseload and flexible load profiles are presented in Figure 3 and in Table 4.

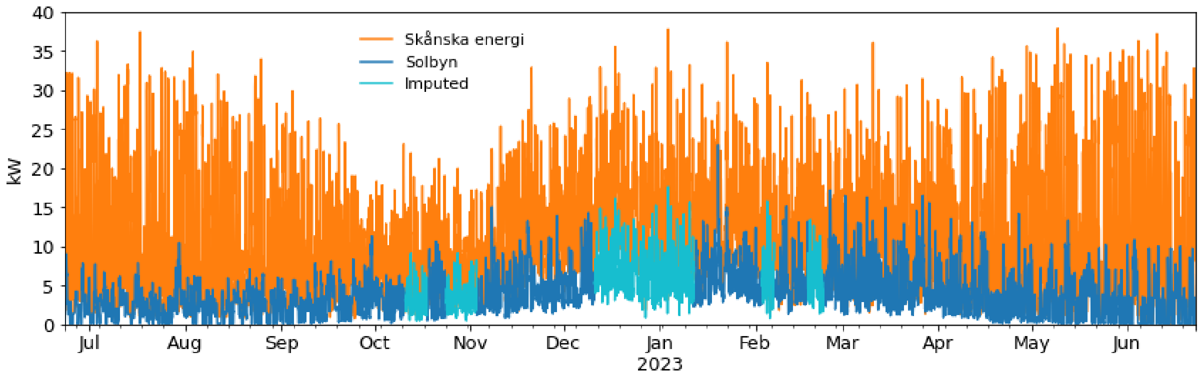


Figure 3: Baseload hourly energy consumption profile in orange and flexible load in blue, between 23 June 2022 and 22 June 2023.

The "Net Flex" profile is calculated from the Flexible profile where the solar power produced behind the meter is subtracted from the Flexible load profile. It represents the net burden of the flexible resources on the local distribution grid.

Table 4: Baseload, Flexible and Net Flexible energy consumption profiles.

Description	Baseload	Flexible	Net Flex
Annual energy consumption (MWh)	66.3	36.9	29.5
Average power demand (kWh/h)	7.6	4.2	3.4
Peak power demand (kWh/h)	37.8	23.0	23.0
Load factor (%)	20.1	18.3	14.6

The “Net Flex” profile is presented in Figure 4 and its load duration curve is presented in Figure 5. This profile represents the flexible demand on site minus the solar production behind the meter. These curves form the basis from which to evaluate the impact of the control strategies.

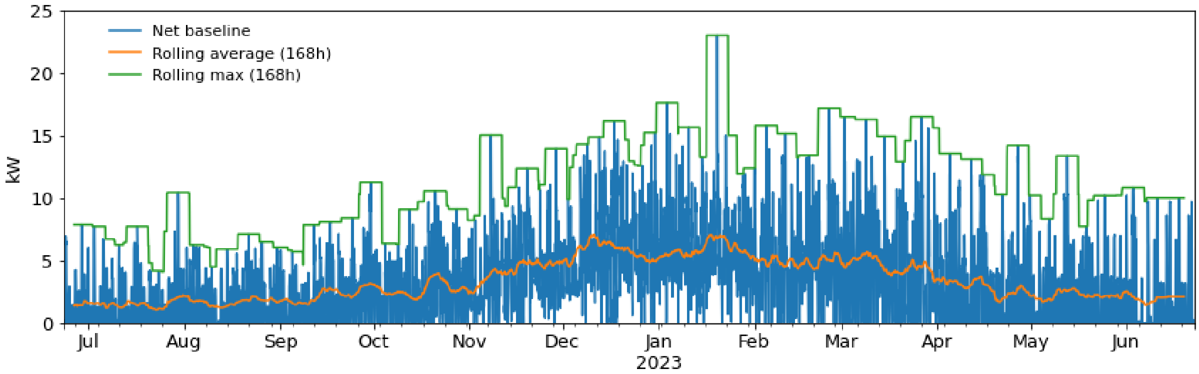


Figure 4: The flexible energy consumption profile.

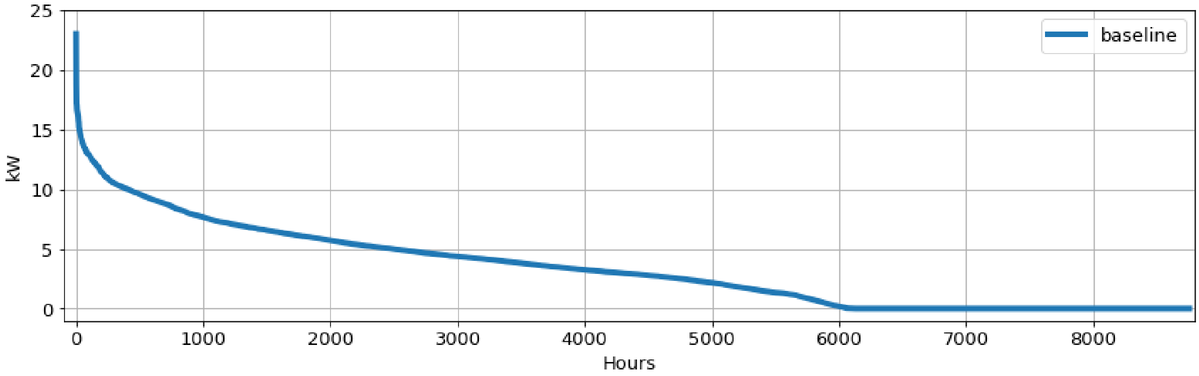


Figure 5: Flexible energy consumption profile load duration curve.

3.2 Energy consumption analysis

When evaluated over the whole year, or at time of peak demand, EV energy consumption is the main driver underpinning the Solbyn load profile. Specifically, Figure 6 highlights how EVs account for 63% of the BRF’s energy consumption, and Figure 7 highlights how EVs also account for 84% of the BRF’s peak power demand, excluding residential demand. Over the five highest peaks in the sample year, EV power consumption accounts for between 78% and 86% of the demand during peak load hours.

It follows therefore that the bulk of the cost reductions would come from appropriately managing the EV load.

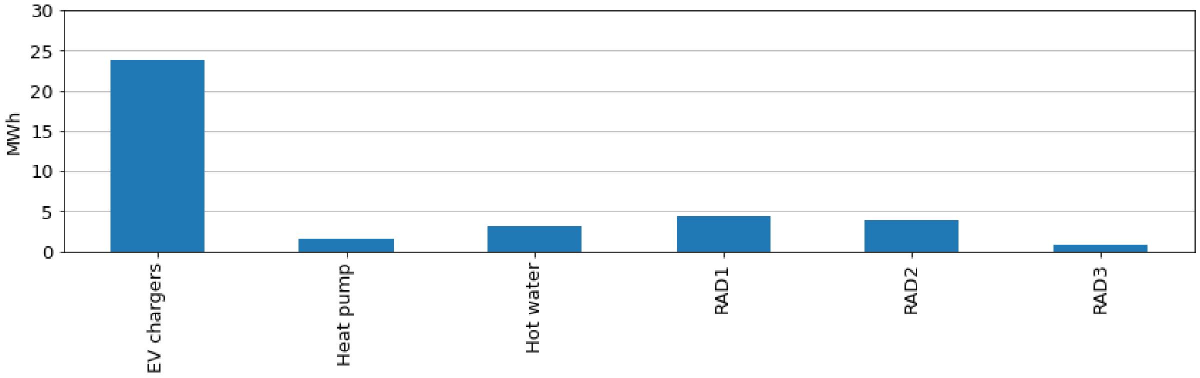


Figure 6: Total energy consumption by appliance between 23 June 2022 and 22 June 2023.

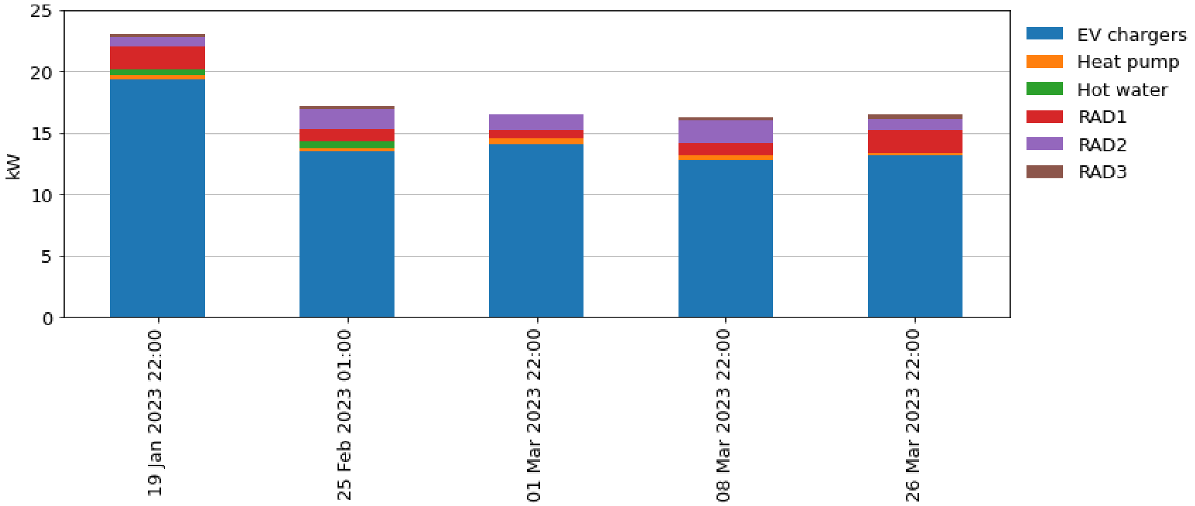


Figure 7: Power consumption by appliance at time of peak load.

3.3 Hybrid control strategy

Several control strategies were considered as part of this project and the results are presented in Appendix C. This section presents the results from the hybrid control strategy only, as it is the most promising from the perspective of both reducing peaks and increasing the self-consumption of energy produced on site.

As discussed in the previous section, peak power consumption is best managed through regulating the instantaneous power consumption of the EV charging. Additionally, limiting the power draw from the grid, by ensuring the battery provides a power guard above a set threshold is also a promising strategy in terms of reducing power peaks. This hybrid strategy therefore combines the two approaches:

- A maximum of three EVs are permitted to charge at once, all other EV charging requests within the fleet are placed in a queue,
- A power guard limit of 12.5 kW is implemented such that the battery provides all power requirements above that threshold.

The results of this control strategy are presented in Figures 8 and 9 below. In both cases, the blue line represents the measured flexible load profile, whilst the orange highlights the net demand profile after the introduction of the hybrid control strategy. In particular, the operation of the battery increases the solar self-consumption such that energy demand is reduced by 14%, whilst the regulated EV charging results in a 10 kW drop to peak power consumption.

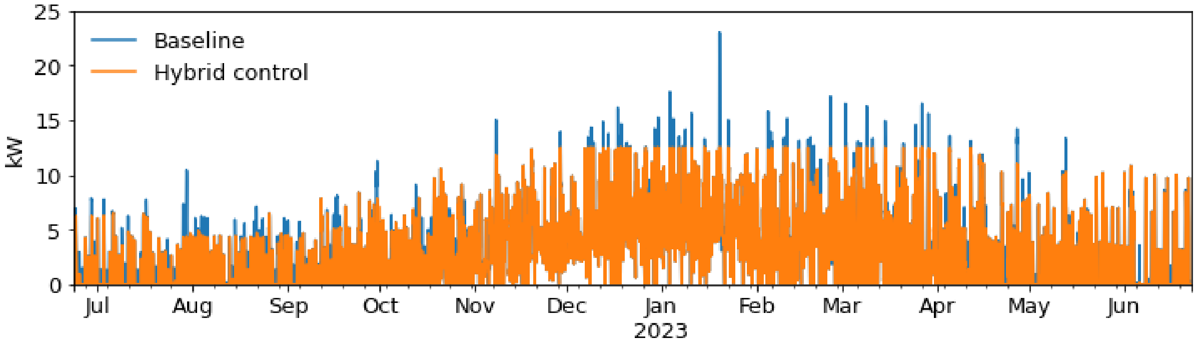


Figure 8: Solbyn load profile, with and without the control strategy (orange and blue respectively).

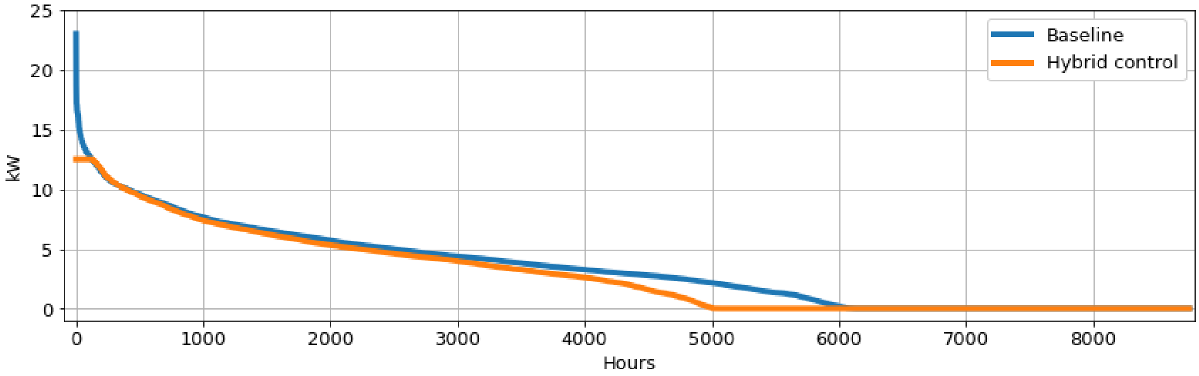


Figure 9: Solbyn load duration curve, with and without the control strategy (orange and blue respectively).

Under such operational conditions, the battery is capable of increasing energy self-consumption by almost 4 MWh annually and the peak power demand by 10.5 kW. This has the effect of increasing the load factor by nine percentage points. This information is present in Table 5.

Table 5 also provides a comparison between the hybrid control strategy and the two other control strategies considered as part of this research project, the time-based and demand-limit control:

- The timer strategy applies a 10% energy reduction to the hourly energy consumed by the radiators. This means that the radiators consume 90% of the measured consumption. In short, most energy savings would occur over winter at the time where they are needed the most.
- In the power-guard strategy the battery remains idle unless it is called upon to discharge power during peak times. The power-guard in this example is set at 15 kW. Therefore, the battery will discharge at any time when the power demand exceeds that value.

Table 5: Comparison of the "net flexible", radiator 90%, power-guard and hybrid energy profiles.

Load profile	**Net Flexible**	**Radiators 90%**	**Power-guard**	**Hybrid**
Annual consumption (MWh)	29.5	28.7	29.4	25.4
Average power demand (kW)	3.4	3.3	3.4	2.9
Peak power demand (kW)	23.0	22.7	17.0	12.5
Load factor (%)	14.6	14.4	19.8	23.2

In practice, regulating EV power consumption may occur in ways other than limiting the number of fleet vehicles that can charge at once: vehicles could be charged at rates below capacity for example. Further research is required to better understand how best to manage fleet EV charging. Importantly, the business model of the charge point operators is likely to be a key influential factor. The methodology provides a proxy to this research, in the knowledge that two different charging regimes were witnessed within our EV charging profiles dataset. Specifically, the orange line on Figure 10 below highlights how the energy consumed for charging EVs remains steady when considered over a two-week rolling period. This suggests that EV usage patterns remain relatively steady over time. The green line, however, which tracks the rolling two-week peak power consumption from EVs is generally lower before October 2022 than after that month. A limit restricting the power draw was implemented before that time because the residential EV drivers were complaining that their vehicles were not charging at full capacity before then. This change in consumption pattern highlights that it is practically possible to charge an EV whilst minimizing peak power consumption. It may however require the users to accept new charging habits.

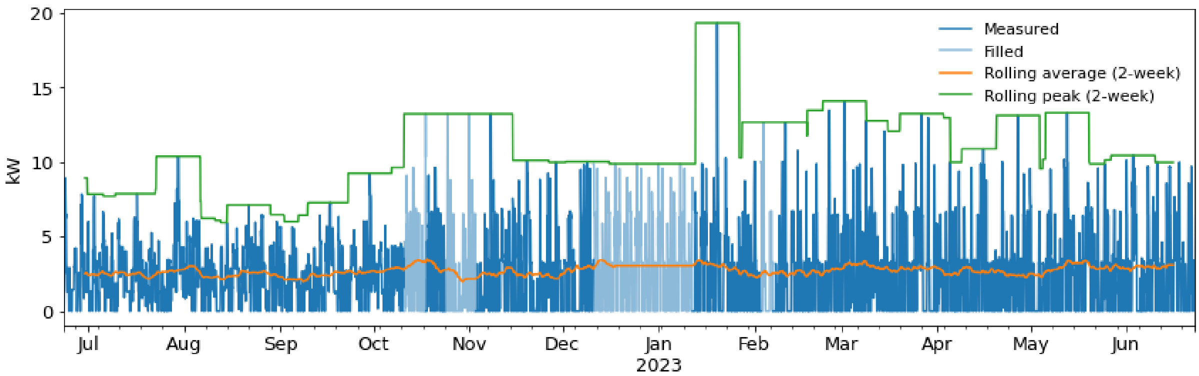


Figure 10: Combined fleet EV charging profile at the site.

3.4 Electricity tariffs

The calculations in this chapter of the electricity tariffs and purchased electricity are based on the equations in Chapter 2.3.

3.4.1 Baseline

Since the demo site is in southern Sweden SE4 two tariffs are used to compare the cost reductions from the price area. One energy-based and one power-based tariff is applied to the baseload energy profile.

Table 6: Electricity tariff annual cost for baseload profile.

Year	**Energy tariff (SEK)**	**Power tariff (SEK)**
2020	106056	118075
2021	157432	149268
2022	222105	201134

Since the control strategies are compared based on the annual cost reductions, the savings from flexible assets is calculated for the “Net Flex” profile highlighted in Chapter 3.1. This is because the static load (baseload, orange graph in Figure 3) is the same throughout the year and the only cost reductions comes from the control of the flexible resources. The following Table 7 is the basis for the cost reductions.

Table 7: Electricity tariff annual cost for net flexible load profile.

Year	**Energy tariff (SEK)**	**Power tariff (SEK)**
2020	63595	62056
2021	85800	84261
2022	115060	113521

3.4.2 Cost reductions

In the Table 8 below the total annual cost is presented for the different control strategies. Base is the net flexible load, C1 – timer, C2 – power guard, C3 – hybrid strategy. (E) is energy tariff, (P) power.

Table 8: Electricity tariff annual cost for control strategies C1, C2, C3.

Year	**Base (E)**	**Base (P)**	**C1 (E)**	**C1 (P)**	**C2 (E)**	**C2 (P)**	**C3 (E)**	**C3 (P)**
2020	63595	62056	62708	61022	63551	60737	59123	53144
2021	85800	84261	84283	82597	85741	82926	78903	72924
2022	115060	113521	112842	111156	114965	112151	103321	97342

In Figure 11 below the cost reductions are illustrated for the energy and power tariff.

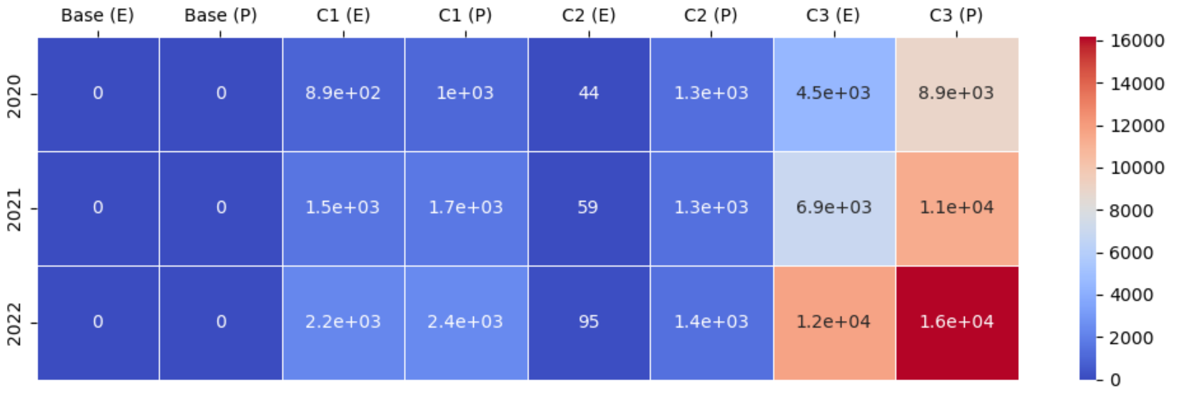
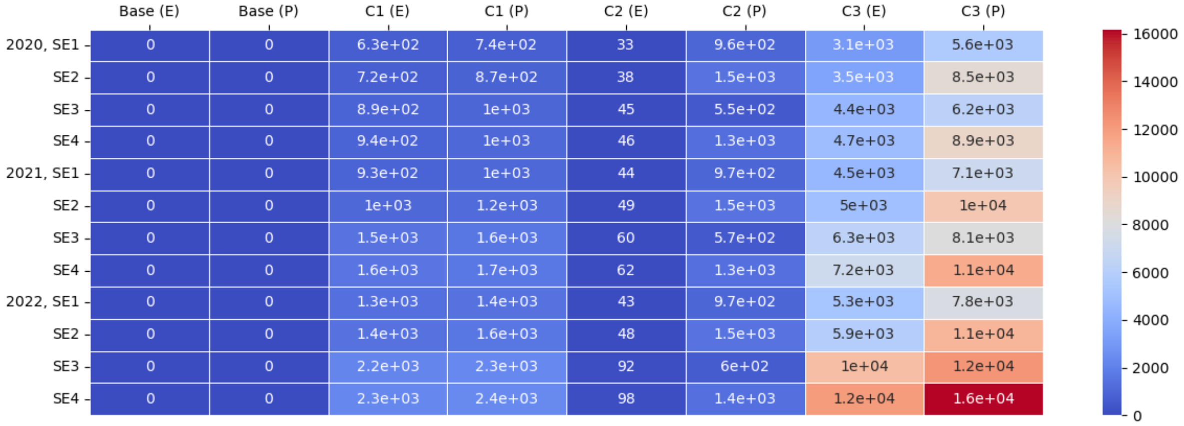


Figure 11: Annual cost reductions for control strategies C1, C2 and C3 compared to base.

The cost reductions for the different control strategies differ between 1-14% per year. Control strategy 1 assumes that the radiators can be turned off 10% of the time compared to baseline and offer modest savings between 1-2%. The assumption is that the total heat load keeps the temperature stable at 20°C and a 10% reduction sets it to the minimum comfort level of 18°C. Control strategy 2 utilizing a power guard offer negligible cost reductions on the energy tariff and modest cost reductions on the power tariff around 1.2%. Control strategy 3 utilizing the battery combined with peak shaving offer the best cost reductions potential of the three options between 7-14%, with an increase in annual cost reductions in the power tariff compared to the energy tariff.

3.4.3 *Sensitivity analysis*

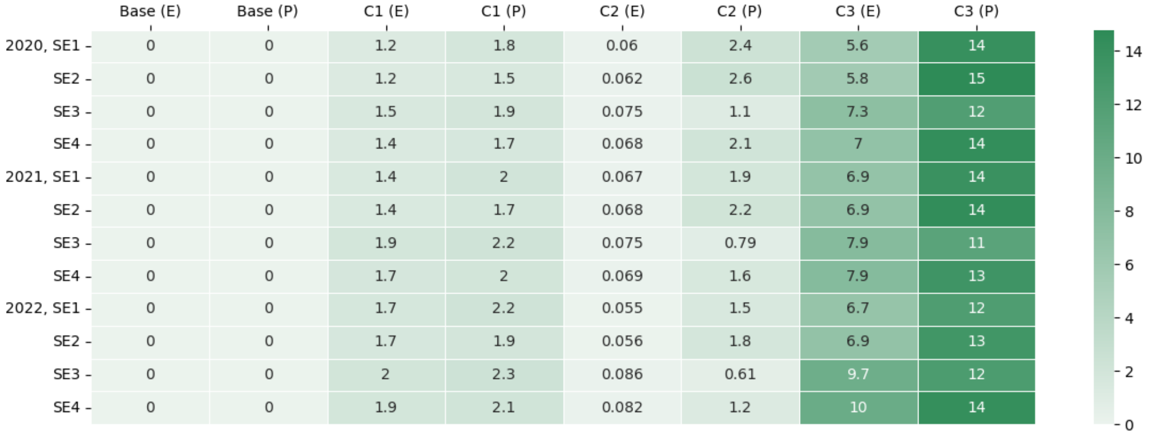
The results for the single energy- and power tariff are extended in this section. 83 energy tariffs have been analysed from the different price areas in Sweden, 4 from SE1, 6 from SE2, 47 from SE3 and 26 from SE4. In Figure 12 below the average cost reductions are illustrated for the different price regions. For the distribution in annual cost of the baseload and net flex energy profiles refer to Appendix C.



	Base (E)	Base (P)	C1 (E)	C1 (P)	C2 (E)	C2 (P)	C3 (E)	C3 (P)
2020, SE1	0	0	6.3e+02	7.4e+02	33	9.6e+02	3.1e+03	5.6e+03
SE2	0	0	7.2e+02	8.7e+02	38	1.5e+03	3.5e+03	8.5e+03
SE3	0	0	8.9e+02	1e+03	45	5.5e+02	4.4e+03	6.2e+03
SE4	0	0	9.4e+02	1e+03	46	1.3e+03	4.7e+03	8.9e+03
2021, SE1	0	0	9.3e+02	1e+03	44	9.7e+02	4.5e+03	7.1e+03
SE2	0	0	1e+03	1.2e+03	49	1.5e+03	5e+03	1e+04
SE3	0	0	1.5e+03	1.6e+03	60	5.7e+02	6.3e+03	8.1e+03
SE4	0	0	1.6e+03	1.7e+03	62	1.3e+03	7.2e+03	1.1e+04
2022, SE1	0	0	1.3e+03	1.4e+03	43	9.7e+02	5.3e+03	7.8e+03
SE2	0	0	1.4e+03	1.6e+03	48	1.5e+03	5.9e+03	1.1e+04
SE3	0	0	2.2e+03	2.3e+03	92	6e+02	1e+04	1.2e+04
SE4	0	0	2.3e+03	2.4e+03	98	1.4e+03	1.2e+04	1.6e+04

Figure 12: Average annual cost reductions in SEK for control strategies C1, C2, C3 compared to base in SE1-4.

The cost reductions for the different control strategies differ between 630-16000 SEK per year. Control strategy 1 utilizing heat loads offer cost reductions of 630-2400 SEK for SE1-4. Control strategy 2 utilizing a power guard offer poor cost reductions on the energy tariff for all regions and similar cost reductions to C1 on the power tariff 550-1500 SEK. Control strategy 3 utilizing the battery combined with peak shaving offer the best cost reductions potential of the three options between 3100-16000 SEK. In SE1 the cost reductions were 3100-7800 SEK, SE2 3500-11000 SEK, SE3 4400-12000 SEK and SE4 4700-16000 SEK. In Figure 13 cost reductions are shown for the price regions in percent of base.



	Base (E)	Base (P)	C1 (E)	C1 (P)	C2 (E)	C2 (P)	C3 (E)	C3 (P)
2020, SE1	0	0	1.2	1.8	0.06	2.4	5.6	14
SE2	0	0	1.2	1.5	0.062	2.6	5.8	15
SE3	0	0	1.5	1.9	0.075	1.1	7.3	12
SE4	0	0	1.4	1.7	0.068	2.1	7	14
2021, SE1	0	0	1.4	2	0.067	1.9	6.9	14
SE2	0	0	1.4	1.7	0.068	2.2	6.9	14
SE3	0	0	1.9	2.2	0.075	0.79	7.9	11
SE4	0	0	1.7	2	0.069	1.6	7.9	13
2022, SE1	0	0	1.7	2.2	0.055	1.5	6.7	12
SE2	0	0	1.7	1.9	0.056	1.8	6.9	13
SE3	0	0	2	2.3	0.086	0.61	9.7	12
SE4	0	0	1.9	2.1	0.082	1.2	10	14

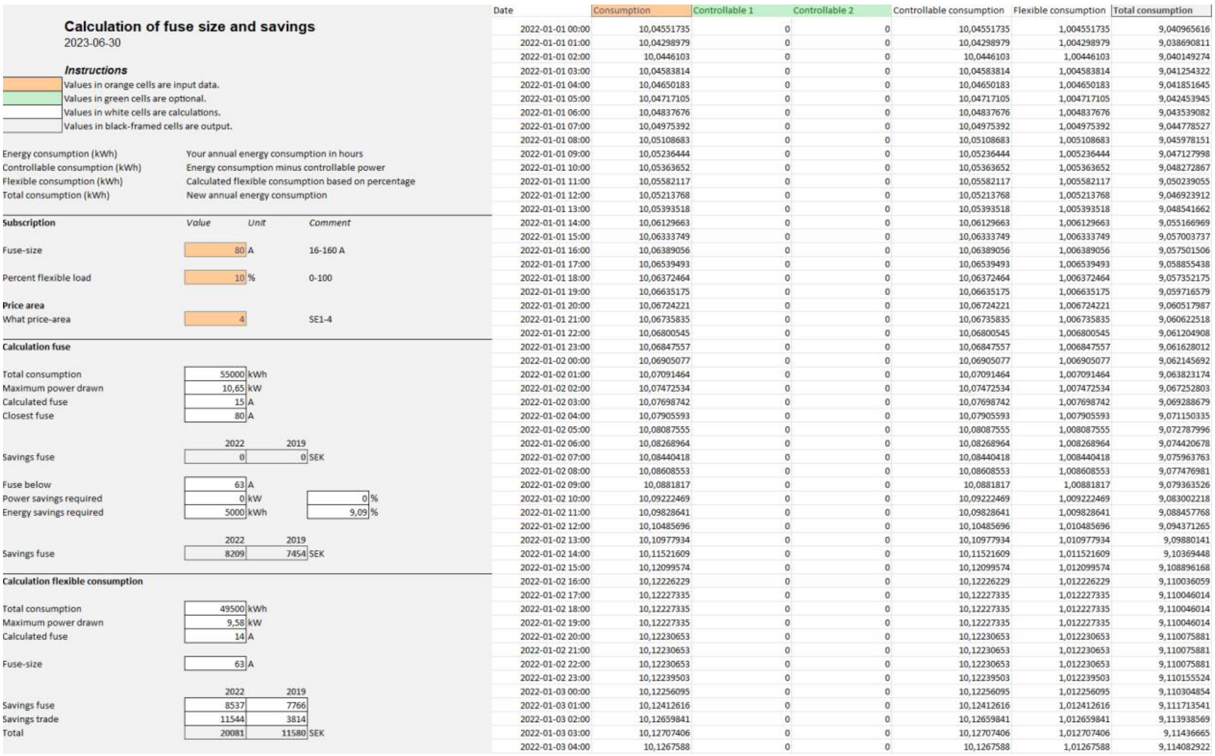
Figure 13: Average annual cost reductions in percent of base for control strategies C1, C2, C3 in SE1-4.

The cost reductions for the different control strategies differ between 1-14% per year. Control strategy 1 utilizing heat loads offer cost reductions of 1.2-2.3% for SE1-4. Control strategy 2 utilizing a power guard offer poor cost reductions on the energy tariff for all regions and similar cost reductions to C1 on the power tariff 1.1-2.6%. Control strategy 3 utilizing the battery combined with peak shaving offer the best cost reductions potential of the three options between 5.6-15%. In SE1 the cost reductions were 5.6-14%, SE2 5.8-15%, SE3 7.3-12% and SE4 7-14%.

3.5 Cost reductions tool

The project resulted in a spreadsheet to estimate the cost reductions of a building based on its current fuse subscription level and estimated flexible load. The user can themselves enter values that suit their own needs. The recommended min and max values range is provided. For other parameters outside the range errors can occur. Orange inputs are obligatory, green is optional, white are calculations and grey are outputs.

The spreadsheet is as presented in Figure 14 below.



Calculation of fuse size and savings
2023-06-30

Instructions

🟧	Values in orange cells are input data.
🟩	Values in green cells are optional.
☐	Values in white cells are calculations.
☐	Values in black-framed cells are output.

Energy consumption (kWh)	Your annual energy consumption in hours
Controllable consumption (kWh)	Energy consumption minus controllable power
Flexible consumption (kWh)	Calculated flexible consumption based on percentage
Total consumption (kWh)	New annual energy consumption

Subscription	*Value*	*Unit*	*Comment*
Fuse-size	80	A	16-160 A
Percent flexible load	10	%	0-100
Price area			
What price-area	4		SE1-4

Calculation fuse

Total consumption	55000	kWh		
Maximum power drawn	10,65	kW		
Calculated fuse	15	A		
Closest fuse	80	A		
	2022	2019		
Savings fuse	0	0	SEK	
Fuse below	63	A		
Power savings required	0	kW	0	%
Energy savings required	5000	kWh	9,09	%
	2022	2019		
Savings fuse	8209	7454	SEK	

Calculation flexible consumption

Total consumption	49500	kWh	
Maximum power drawn	9,58	kW	
Calculated fuse	14	A	
Fuse-size	63	A	
	2022	2019	
Savings fuse	8537	7766	
Savings trade	11544	3814	
Total	20081	11580	SEK

Date	Consumption	Controllable 1	Controllable 2	Controllable consumption	Flexible consumption	Total consumption
2022-01-01 00:00	10,04551735	0	0	10,04551735	1,004551735	9,040965616
2022-01-01 01:00	10,04298979	0	0	10,04298979	1,004298979	9,038690811
2022-01-01 02:00	10,0446103	0	0	10,0446103	1,00446103	9,040149274
2022-01-01 03:00	10,04583814	0	0	10,04583814	1,004583814	9,041254322
2022-01-01 04:00	10,04650183	0	0	10,04650183	1,004650183	9,041851645
2022-01-01 05:00	10,04717105	0	0	10,04717105	1,004717105	9,042453945
2022-01-01 06:00	10,04837676	0	0	10,04837676	1,004837676	9,043539082
2022-01-01 07:00	10,04975392	0	0	10,04975392	1,004975392	9,044778527
2022-01-01 08:00	10,05108683	0	0	10,05108683	1,005108683	9,045978151
2022-01-01 09:00	10,05236444	0	0	10,05236444	1,005236444	9,047127998
2022-01-01 10:00	10,05363652	0	0	10,05363652	1,005363652	9,048272867
2022-01-01 11:00	10,05582117	0	0	10,05582117	1,005582117	9,050239055
2022-01-01 12:00	10,05213768	0	0	10,05213768	1,005213768	9,046923912
2022-01-01 13:00	10,05393518	0	0	10,05393518	1,005393518	9,048541662
2022-01-01 14:00	10,06129663	0	0	10,06129663	1,006129663	9,055166969
2022-01-01 15:00	10,06333749	0	0	10,06333749	1,006333749	9,057003737
2022-01-01 16:00	10,06389056	0	0	10,06389056	1,006389056	9,057501506
2022-01-01 17:00	10,06539493	0	0	10,06539493	1,006539493	9,058855438
2022-01-01 18:00	10,06372464	0	0	10,06372464	1,006372464	9,057352175
2022-01-01 19:00	10,06635175	0	0	10,06635175	1,006635175	9,059716579
2022-01-01 20:00	10,06724221	0	0	10,06724221	1,006724221	9,060517987
2022-01-01 21:00	10,06735835	0	0	10,06735835	1,006735835	9,060622518
2022-01-01 22:00	10,06800545	0	0	10,06800545	1,006800545	9,061204908
2022-01-01 23:00	10,06847557	0	0	10,06847557	1,006847557	9,061628012
2022-01-02 00:00	10,06905077	0	0	10,06905077	1,006905077	9,062145692
2022-01-02 01:00	10,07091464	0	0	10,07091464	1,007091464	9,063823174
2022-01-02 02:00	10,07472534	0	0	10,07472534	1,007472534	9,067252803
2022-01-02 03:00	10,07698742	0	0	10,07698742	1,007698742	9,069288679
2022-01-02 04:00	10,07905593	0	0	10,07905593	1,007905593	9,071150335
2022-01-02 05:00	10,08087555	0	0	10,08087555	1,008087555	9,072787996
2022-01-02 06:00	10,08268964	0	0	10,08268964	1,008268964	9,074420678
2022-01-02 07:00	10,08440418	0	0	10,08440418	1,008440418	9,075963763
2022-01-02 08:00	10,08608553	0	0	10,08608553	1,008608553	9,077476981
2022-01-02 09:00	10,0881817	0	0	10,0881817	1,00881817	9,079363526
2022-01-02 10:00	10,09222469	0	0	10,09222469	1,009222469	9,083002218
2022-01-02 11:00	10,09828641	0	0	10,09828641	1,009828641	9,088457768
2022-01-02 12:00	10,10485696	0	0	10,10485696	1,010485696	9,094371265
2022-01-02 13:00	10,10977934	0	0	10,10977934	1,010977934	9,09880141
2022-01-02 14:00	10,11521609	0	0	10,11521609	1,011521609	9,10369448
2022-01-02 15:00	10,12099574	0	0	10,12099574	1,012099574	9,108896168
2022-01-02 16:00	10,12226229	0	0	10,12226229	1,012226229	9,110036059
2022-01-02 17:00	10,12227335	0	0	10,12227335	1,012227335	9,110046014
2022-01-02 18:00	10,12227335	0	0	10,12227335	1,012227335	9,110046014
2022-01-02 19:00	10,12227335	0	0	10,12227335	1,012227335	9,110046014
2022-01-02 20:00	10,12230653	0	0	10,12230653	1,012230653	9,110075881
2022-01-02 21:00	10,12230653	0	0	10,12230653	1,012230653	9,110075881
2022-01-02 22:00	10,12230653	0	0	10,12230653	1,012230653	9,110075881
2022-01-02 23:00	10,12239503	0	0	10,12239503	1,012239503	9,110155524
2022-01-03 00:00	10,12256095	0	0	10,12256095	1,012256095	9,110304854
2022-01-03 01:00	10,12412616	0	0	10,12412616	1,012412616	9,111713541
2022-01-03 02:00	10,12659841	0	0	10,12659841	1,012659841	9,113938569
2022-01-03 03:00	10,12707406	0	0	10,12707406	1,012707406	9,11436665
2022-01-03 04:00	10,1267588	0	0	10,1267588	1,01267588	9,114082922

Figure 14: Overview of energy cost reductions tool.

The input parameters are described in Table 9 with example values.

Table 9: Input parameters.

Parameter	**Value**	**Min-Max**
Fuse-size (A)	80	16-160
Percent flexible load (%)	10	0-100
Price-area	4	1-4
Load (kWh/h)	-	-

The current fuse size is used as the basis of the cost reductions calculation, in the example the current subscription level is 80 A. The percentage of flexible load is the assumed load available to reduce the total load. The price area influences the purchased electricity calculation from SE1-4.

In the 'Consumption' column the hourly load is entered from January-December with size 1-8760 in kWh. 'Controllable 1,2' are optional columns if a certain load pattern is known and can be excluded from the flexible load, e.g. EV charging.

The first result box only utilizes the current fuse size and calculates how close the user is to an underlying fuse and what is required in terms of energy and power to lower the subscription. Therefore, no traded electricity is calculated since it is only based on the column 'Consumption'. The result is SEK saved annually on a lower fuse. In the example calculation, the building has the correct fuse sizing 80 A, but can be lowered to 63 A with a 5000 kWh reduction in energy. The new annual payment would then be for a load of 50000 kWh, matching the tariff 63 A, 50000 kWh, 44 kWp.

The second result box is based on the percentage of flexible load and 'Controllable 1,2'. The calculation includes cost reductions on purchased electricity and the result is SEK saved annually on a potentially lower fuse and traded electricity. The input was set to 10% flexible load which yielded both a lowered fuse subscription and cost reductions in purchased electricity.

A detailed description of two examples is provided in Appendix D, one without and one with EV charging.

4 Discussion

This chapter presents a comprehensive discussion on active load management, which has been a significant focus of this project. Simulations have been conducted to evaluate and assess the effectiveness and feasibility of active load management strategies. This discussion chapter aims to analyze the findings, highlight key insights, and provide recommendations for further implementation and research.

The simulations and evaluations have demonstrated several benefits of active load management. By implementing control strategies such as time-based control, demand limit-based control, and real-time control, households can increase self-consumption and achieve cost reductions. The utilization of flexible resources allows for optimized energy consumption patterns and load shedding during peak demand periods. Active load management can also contribute to enhanced grid stability and improved energy efficiency. The evaluation of different control strategies revealed their varying effectiveness in achieving energy savings and load optimization. Time-based control demonstrated modest cost reductions in regulating household heat loads. Demand limit-based control was utilized in cutting peak demand, but the cost reductions in power were poor compared to the cost reductions in energy. Real-time control, incorporating a battery system and optimized dispatch, exhibited the highest level of flexibility and adaptability in maximizing self-consumption.

Pricing and cost reduction

Considering the pricing system in Sweden, different electricity tariffs were used in the evaluation of the load profiles. By applying this framework, the increase in self-consumption of energy, energy savings in the case of regulating the radiator operations and the reduction in power peaks were analyzed for each control intervention. The analysis included comparing electricity bills, grid fees and purchased electricity for different scenarios. It allowed for understanding the cost implications of electricity consumption patterns. The findings provided insights into potential cost reductions, the effectiveness of different tariffs, and the variations in grid fees between electricity network companies and price areas. The findings pointed at the biggest reduction in customer cost came from energy saving and not peak shaving.

IT hardware and telecommunications

One of the lessons learned from the project was the importance of having control over hardware and reducing dependence on external parties. This became clear several times during the project. First, the project was hit hard by the fact that the basic measurement hardware was not in place at the start of the project and data collection had to wait. In addition, there was a continuous problem with network clutter during the project (changing IP addresses, etc.). Since the router and connection were provided by the site, the project was sometimes in the hands of the IT manager correcting the router. This in turn meant that the project experienced long response times before issues were resolved and work could resume. This was noticed, among other things, when the first router that was used crashed. The logging system then lost contact with most resources it communicated with over the router. In addition, the system could not be accessed remotely as this type of communication took place through the same router. This meant that no data could be retrieved by the project participants during the period the router broke down until a new one was in place. In this way, the importance of being able to be responsible for internet access and router became clear.

Another lesson learned was that quality is probably better than quantity when it comes to sensors. During the project, there were major problems with the reliability of the simpler temperature meters that were purchased. On the one hand, there was some uncertainty in the accuracy of the measurement values, but above all there were problems with the reliability of the connection of the sensors. The sensors were connected via the Zigbee wireless communication protocol and tended to lose connection. In addition, the sensors were battery powered and at risk of being discharged. This led to longer periods where temperature data were missing. A better alternative would have been to procure a smaller number of temperature meters that were instead of a higher quality and connected via cable like the energy meters that were used during the project.

The importance of choosing a platform for software was also something that became clear during the project. The platform that was in place at the start of the project was inherited from previous projects. The platform was made up of a NAS unit, which was originally intended only to store data. Instead, the NAS unit was also responsible for both data processing and control. This solution lacked a clear structure and was very flawed. Due to the limitations of the NAS device, the decision was made to move all software to a new platform in the form of a more traditional server. This choice was probably the right decision but at the wrong time. The hardware was installed in December 2022 just before the holidays. The concern with this was that even if the hardware was in place, the software had to be manually moved over and patched afterwards to the new hardware. These changes were then delayed, which resulted in a period where nothing was logged. The router also crashed during this period and the adjustments had to be delayed further until a new router was in place.

Finally, there was a major limitation in which controllable resources were available within the project. The only way to limit the power draw on site in practice was to either limit the car chargers or to turn off one of the relays of the S7-1200 PLC unit. In addition, certain resources such as the heat pump did not appreciate being switched off completely without warning, which further limited the possibilities available for power control. In conclusion, there were extremely limited opportunities to limit the power output in practice.

Active load control

Based on the data collected for as part of this research project, regulating EV fleet charging appears to be the most promising solution to regulating power peaks in multi-family residential associations. There are several reasons why this would be the case:

- EVs have been shown to be the main driving factor driving peak loads.
- Energy consumption for EVs is steady through and the year: it is not seasonal.
- EVs are typically parked idly at night, at their designated docking station.

Combined, each of these factors highlight an opportunity to distribute vehicle charging in time. Specifically, the largest peak load within the dataset occurred on the 19 January 2023 around 10pm. It occurred because six of the twelve charge points were discharging power at once. This was a rare event occurring for only 0.1% of the minutes in the year, and yet, it caused the largest power peak.

Algorithmically predicting when the peaks will occur is an exercise fraught with difficulties and inaccuracies. Contrastingly, ensuring the power distribution across EV charging stations within the same fleet follows a fixed set of rules and principles is easy to implement, effective in its objective, and inexpensive to maintain. In fact, the Solbyn BRF had a limit that was successful in restricting the power draw from EVs before October 2022, which can be seen the data. The main issue from this form of load control was that one EV owner was complaining that their vehicles was not charging at full capacity when the limit was implemented. Active load management of EVs within a fleet is likely therefore to require its users to accept specific charging habits: for example, keeping their vehicles always plugged in when parked in their allocated bays.

As for other load control strategies, there are pragmatic reasons why they are not as effective in managing peak loads in the BRF setting:

- Time based control strategies are limited to appliances that are negligible in terms of their contribution to the peak energy demand of the BRF. Additionally, these appliances typically provide a heating service that cannot be reduced significantly for either comfort or health and safety reasons.
- A power-guard is only a partial failsafe in that it is limited by the availability and the nominal power rating of a battery to cover the peaks. Not all BRFs would choose to install a battery and there is no full guarantee that power demand would never exceed the power-guard.

Future research

To further enhance the effectiveness of active load management, several areas warrant future research. This includes investigating advanced control algorithms to optimize load scheduling and forecasting. Additionally, exploring the integration of renewable energy sources, such as solar panels and electric vehicle charging stations, can enhance the potential for self-consumption and grid interaction. Further studies on consumer behavior, engagement strategies, and demand response programs can also provide valuable insights into maximizing the benefits of active load management.

While active load management offers numerous benefits, it is essential to acknowledge the challenges and limitations associated with its implementation. One challenge lies in the need for robust communication infrastructure and smart metering systems to enable real-time control and monitoring. Additionally, behavioral factors, such as user acceptance and engagement, can impact the success of load management programs. The scalability and interoperability of control systems across diverse household setups and appliances also pose technical challenges that require careful consideration.

5 Conclusions

Active load management, as evaluated through simulations in a virtual environment, has demonstrated its potential as a viable solution for optimizing energy consumption, reducing costs, and promoting sustainable energy practices. The findings emphasize the significance of control strategies, integration of electricity tariffs, and addressing associated challenges for successful implementation. The main results are that in terms of power drawn from the grid, the EVs are a high percentage charge of the load, therefore focusing on optimal charging/ scheduling is important to reduce the peak load for BRFs. Current power tariffs offer a slight increase in savings as compared to energy-based tariffs. These differences may become more pronounced, offering higher savings with a stricter tariff structure. Active load management has a potential to shift energy consumption patterns, mitigate costs, and foster sustainable energy practices, underscoring the importance of continued research, innovation, and collaboration for its widespread implementation and integration into future energy systems.

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Appendix A - Project site information

Historik för Hårdvara

I detta kapitel kommer den hårdvara som fanns till förfogande inom projektet att beskrivas. Först kommer den befintliga hårdvara som existerade vid projektstart att beskrivas följt av de modifikationer som gjordes under projektets gång.

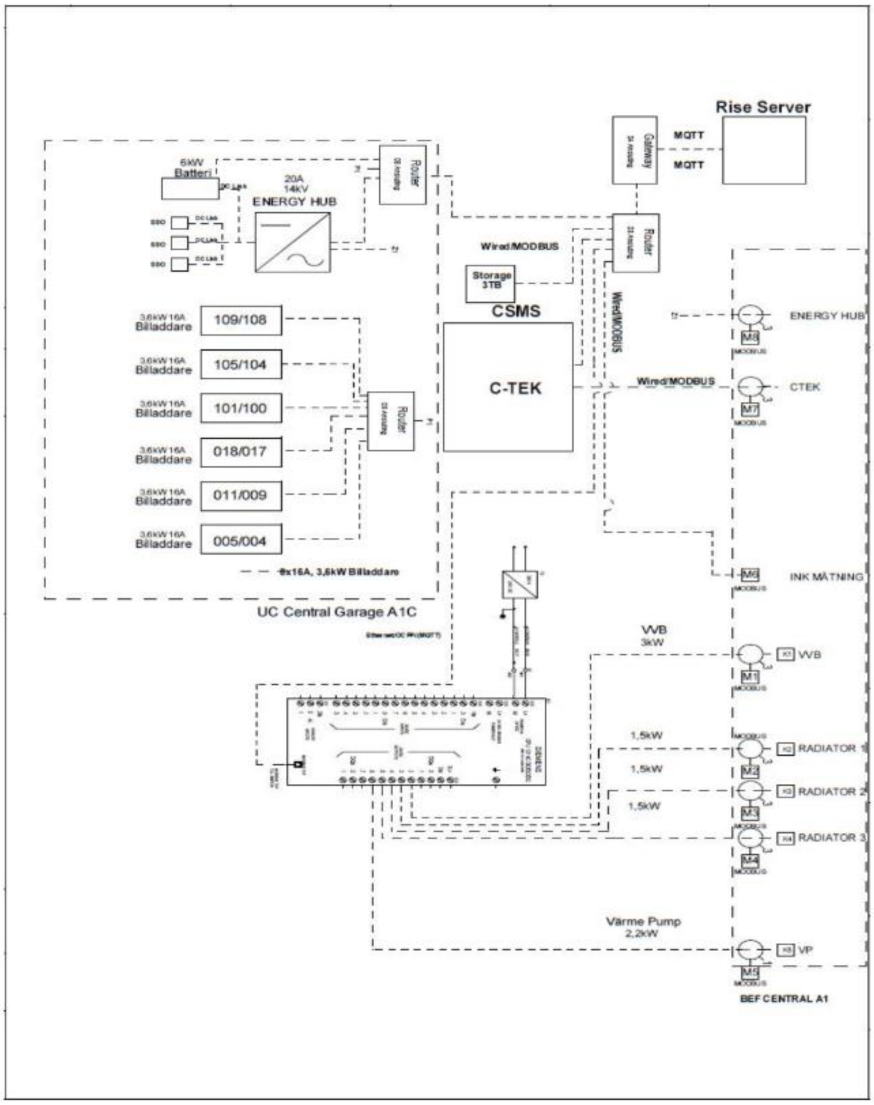
Första versionen

Den första uppsättning av hårdvara som fanns vid Solbyn installerades på uppdrag av RISE genom det tidigare utförda och så kallade CAR-projektet efter offentlig upphandling. Då installationen drog ut på tiden så drabbades även detta projekt av att kritisk hårdvara inte fanns på plats vid projektstart. Tyvärr uppstod dessutom oenigheter kring vad som skulle levereras enligt upphandling för dåvarande projekt. I följande avsnitt detaljeras den uppsättning av hårdvara samt mjukvara som fanns installerad efter förlikning av tidigare projekt, se även en överblicksbild i Figur A1.

Hårdvara

Systemets övergripande delar enligt nedan:

1. Ferroamp EnergyHub Växelriktare 14kVA
2. 3 uppsättningar solceller på 14kWp, 15kWp samt 20kWp
3. Nilar Batteri 15 kWh, 6 kW
4. C-TEK Billaddare 6 stycken 2x3,7 kW
5. C-TEK Nano Grid Kontrollsystem
6. 1 st NEMO 96 HD+ Kwh mätare, modbus TCP/IP
7. 1 st Siemens S7-1200 PLC, modbus TCP
8. 1 st QNAP NAS Lagringsenhet 6TB
9. 5 st Carlo Gavazzi kWh Mätare, modbus TCP/IP



Figur A1: Översikt systemet efter grundinstallation.

Solsystem med batteri

Det fanns 3st uppsättningar med solceller på 14kWp, 15kWp samt 20kWp. Den förstnämnda uppsättningen var även ansluten med 3 st FerroAmp solsträngsoptimerare till en FerroAmp Energyhub växelriktare. Till denna Energyhub fanns även ett 15kWh Nilar batteri anslutet för energilagring.

Billaddare 6 stycken 2x3,7 kW billaddare

Billaddare om 12 stycken uttag med intern belastningsutjämning via CTEKs Nano Grid kontrollsystem installerades.

Energimätare

Det installerades totalt 6 st. energimätare. 5 av märke Carlo Gavazzi, 1 av Nemo, där samtliga använde kommunikationsprotokollet modbus över TCP/IP. Mätarna var installerade för att ge en överblick över de viktigaste energiförbrukarna på anläggningen. Följande förbrukare fick mätare, parentes anger förkortning:

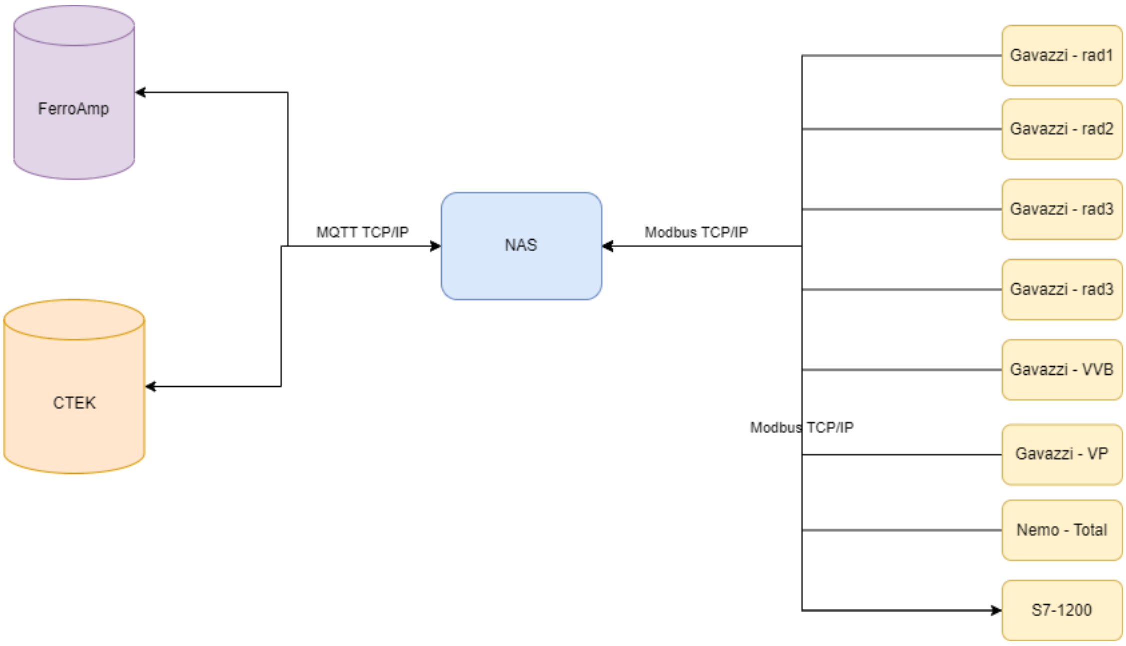
1. Värmepump (VP)
2. Varmvattenberedare (VVB)
3. Radiatorslinga 1 (Rad1)
4. Radiatorslinga 2 (Rad2)
5. Radiatorslinga 3 (Rad3)
6. Total förbrukning (Total)

Siemens S7-1200 PLC

En PLC-styrenhet kopplades med reläer för att kunna bryta strömmen till nummer 1-5 av föregående lista. Detta för att ge någon form av styrbarhet till vilka resurser som skulle kunna kopplas från.

NAS Lagringsenhet

Den sista del av hårdvaran som installerades i det tidigare projektet var den NAS-enhet som skulle ansvara för lagring av mätdata. Denna enhet kom även senare att få ansvaret för styrning som resultatet av en av många kompromisser som fick göras i CAR-projektet. I Figur A2 visas en bild över hur olika enheter var kopplade för att skicka mätdata för lagring hos NAS-enheten. Notera att S7-1200, FerroAmp samt CTEK systemen har dubbelriktade pilar för att indikera möjlighet för styrning.



Figur A2: Översikt över kommunikation för loggning samt styrning.

Mjukvara

NAS-enheten som nämndes tidigare utgjorde den plattform där mjukvara för både loggning samt styrning kördes. I korthet utfördes både loggning samt styrning med hjälpt av script skrivna i Python. Varje enhet som loggades eller styrdes kontrollerades med varsitt script. Alla script placerades i så kallades Docker-containrar. Mätdata lagrades i en InfluxDB databas och all data publicerades även genom en lokal MQTT-broker som kördes på NAS-enheten.

Externa API:er

För att kunna skicka styrkommandon till de styrbara resurserna så skulle dessa skickas till MQTT brokern som fanns på NAS-enheten. Dessa skickades därifrån sedan vidare till korrekt enhet via dess motsvarande Python script. För att styra reläer kunde kommandon för av eller på skickas till S7-1200 PLC-enheten. För att styra batteriet kunde ett Watt-antal specificeras för laddning eller urladdning och skickas via Ferroamp-systemet. Till sist kunde billaddare begränsas till ett visst Ampere tal som angav den maxnivå som ladd-systemet fick använda som helhet.

RISE Studiebesök (Augusti 2021)

Vid det studiebesök som RISE utförde mot slutfasen av den ursprungliga grundinstallationen gjordes en grundinspektion samt installation av nya temperatursensorer. Här gjordes valet att ha flera enkla och billiga sensorer för att få bra täckning över området samt redundans. Sensorerna var av märket Aqara och använde det trådlösa kommunikationsprotokollet ZigBee för att kommunicera. Totalt installerades 15st sensorer, se Figur A3. För att ta emot och avkoda informationen från sensorerna installerades även en Raspberry Pi med en Conbee 2 Zigbee-controller. Informationen skickades sedan till och lagrades på NAS-enheten.

Figur A3: Utplacering av temperatursensorer.

Vid besöket uppdagades det att fastigheten även var försedd med solfångare i anslutning till ackumulatortanken. Det uppmärksammades även att det fanns två uppsättningar med solceller som inte var försedda med effektmätare. Till skillnad från fastighetens tredje uppsättning som uppmättes genom FerroAmp systemet så saknades mätdata för dessa helt. För att bättre få en översikt togs därför beslutet att förse både dessa uppsättningar med solceller med effektmätare. Dessutom skulle både utlopp för ackumulatortanken samt dess tillskott från solfångaren att förses med energimätare.

Summering av installerad hårdvara:

1. Temperatursensor – Aqara Temperature and Humidity Sensor x15
2. Raspberry Pi 4B
    a. Conbee 2 Zigbee-Controller

Studiebesök 2 (Oktober 2022)

För att se till att installationen av nya mätare skulle motsvara de önskemål som fanns så gjordes ett nytt studiebesök tillsammans med hantverkare för att skapa ett så korrekt underlag som möjligt. Under besöket kunde det även konstateras att mätaren för totalt last hade gått sönder. Ett beslut togs även då att även ersätta denna med en ny mätare.

Vid besöket utfördes även en övergripande omorganisation av all hårdvara som fanns på plats. Bland annat installerades ett rack samt en nätverksswitch för att bättre kunna organisera den hårdvara som funnits sedan tidigare, se Figur A4.

Figur A4: Ny organisation av hårdvara med nytt rack samt nätverksswitch.

Det installerades även Aqara Smart Plugs som likt temperatursensorerna använder Zigbee som kommunikationsprotokoll, se Figur A5. Dessa installerades för att förbättra täckningen av temperatursensorerna då Smart Plugs kan agera brygga och vidarebefordra meddelanden från de sensorer som satt längst ifrån mottagaren.

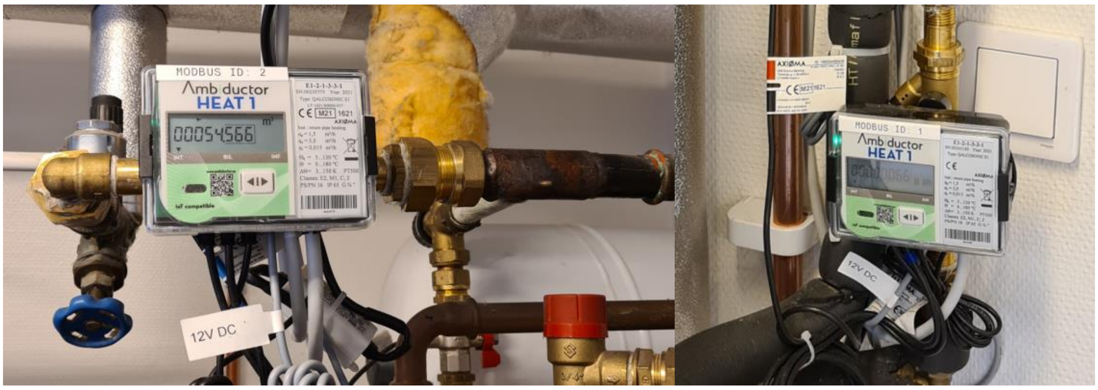
Figur A5: En Aqara Smart Plug.

Summering av installerad hårdvara:

1. Rack
2. Nätverksswitch
3. Aqara Smart Plug x2

Utökad uppsättning mätare (Februari 2022)

För att kunna hålla koll på hur mycket energi som tillfördes från solfångaren samt den totala energiförbrukningen så installerades två stycken energi- och flödesmätare av modell Ambiductor Heat 1. Den första mätte tillförd energi från solfångare till ackumulatortanken och den andra mängden energi som hämtas ut från ackumulatortanken. Båda mätarna kommunicerade över Modbus RTU. För att få över denna information till NAS-enheten så användes en Moxa MGate MB3180-enhet för att konvertera trafiken till Modbus TCP och på så vis integrera med resten av systemet.



Figur A6: Nyinstallerade energimätare vid ackumulatortanken.

Det installerades även en ny energimätare av märket Carlo Gavazzi för att ersätta den tidigare mätaren av total förbrukning då denna som nämnt gått sönder. Då den nya mätaren var av typ Modbus RTU (till skillnad från tidigare) behövdes även här en Moxa MGate för att integrera med systemet. Mätare av samma typ kopplades även till de två uppsättningarna med solceller som inte var kopplade till FerroAmp systemet för att få en mer komplett överblick.

Summering av installerad hårdvara:

1. Ambiductor Heat 1 x2
2. Carlo Gavazzi EM340 kWh Mätare Modbus x3
3. Moxa MGate MB3180 x2

Ny dataplattform (December 2022)

Ett återkommande problem under hela projektets gång var oplanerade strömavbrott som slog ut mätutrustningen. Detta var ett extra stort problem för den NAS-enhet som ansvarade för dataloggning samt lagring. NAS-enheten gick inte att konfigurera på ett sådant sätt att den lyckades återställa sig efter oplanerad förlust av ström. Detta ledde till längre perioder utan mätning till följd av strömavbrott. För att motverka detta problem, ge systemet större stabilitet samt flexibilitet togs beslutet att flytta över loggningsmjukvaran till en traditionell server. En traditionell server gav möjligheten att enklare kunna åtgärda att loggningsprocesser kunde återstarta korrekt vid omstart, planerad eller inte. Dessutom installerades en UPS för att ge ytterligare skydd mot strömavbrott.

En ny dator gav inte bara bättre stabilitet och kontroll över mjukvaran utan även möjlighet att ha större ansvar över nätverkskommunikationen och adresseringen. Den ursprungliga nätverksdesignen gick ut på att all kommunikation gick rakt av på bostadsrättsföreningens nätverk. Det gjorde dels att systemet fick en mellanhand för alla inställningar vad gäller nätverket, dels exponerade alla mätare och deras data för bostadsrättsföreningens nät.

Lösningen på detta blev:

- Skapa ett separat nätverk för givare och annan utrustning i projektet
- Bind samman dessa nätverk genom att konfigurera servern att agera router
- Flytta ansvaret för DHCP-konfiguration (central hantering av adresser) till den nya servern

Summering av installerad hårdvara:

1. Ny dator – ASUS ExperCenter PN64
2. UPS - Powerwalker VI 1200 SHL
3. Kraftfullare switch - Netgear ProSafe GS724Tv4

Ny Router (December 2022)

Slutligen skickades en ny router ner till lokal IT-ansvarig på Solbyn då den dåvarande router som användes på anläggningen hade havererat. Routern var kritiskt både för att kunna ta del av mätdata samt styra.

Summering av installerad hårdvara:

1. Router - TP-link Archer AX6000

Appendix B – Data handling

Skånska Energi

BRF Solbyn is billed monthly from Skånska Energi (SE) for the electricity it uses. The billing is based on the hourly on-site energy consumption and solar production. These are measured by and available for download from SE's online portal. With no missing data points, this dataset is of high quality.

Figure B1 highlights the BRF's net energy consumption profile of the past year as downloaded from SE's online portal. It includes the energy consumption of all the private residences within the BRF, as well as the communal appliances listed in Chapter 2.1.

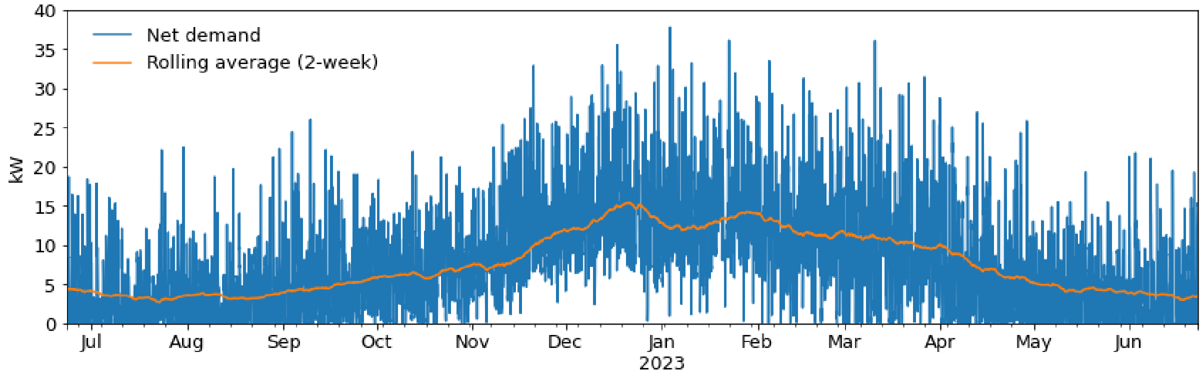


Figure B1: Solbyn net energy demand profile for latest year, recorded by Skånska Energi.

Energy appliances

RISE had access to energy meters installed on several appliances within the BRF facilities. These include the:

- electric vehicle chargers
- heat pump
- hot water boiler
- three radiator rings
- solar panels

The information recorded from these devices contain several gaps in time. Consequently, the following sections of this appendix highlight the methods applied to compensate for the missing values. The gaps are all linked to communication issues that arose as part of the information gathering, which explains why the same gaps are present in each of the time-series below.

Electric vehicle chargers

Six electric vehicle (EV) charge posts are installed at the BRF, each with two corresponding 3.7 kW charge points. A power limit was implemented on the charging system prior to October 2022. Once removed, the vehicle charging rates increased. This is visible in Figure B2 through the higher rolling peaks (green line). Despite this, the energy consumption from EVs charging remains relatively steady throughout the year at around 2.6 kWh each hour (orange line). This would suggest that the resident travel patterns are not dependent on the season and the time of year.

The lighter blue values on Figure B2 highlight the data gaps from the measured time series. Specifically, the timeseries was shifted backwards in time by 168 hours (1-week) to fill the missing values. This process was repeated multiple times until each timestamp within the time series was filled. This method was used for all the time-series mentioned below.

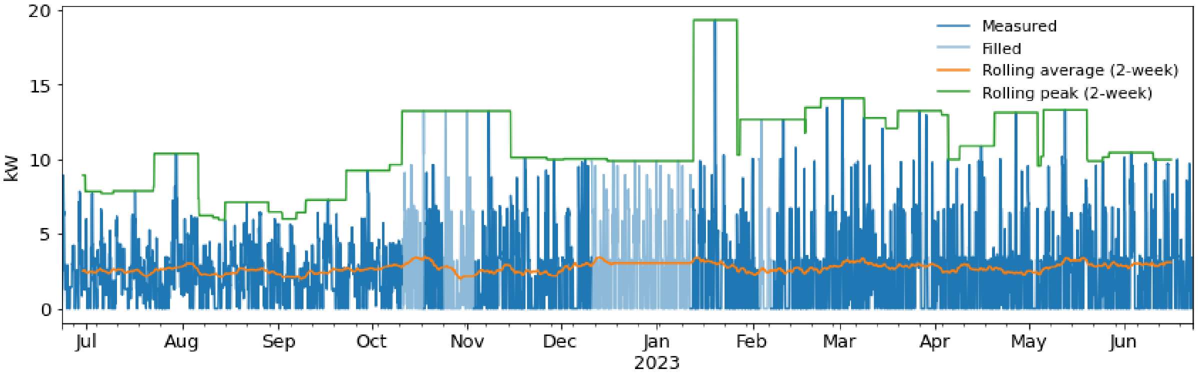


Figure B2: Energy consumption from electric vehicles.

Heat pump

Figure B3 highlights the load profile of the 2.2 kW heat pump installed at the BRF. During the colder months of the year, the heat pump operates a relative steady profile consuming between 0.2 and 0.5 kWh per hour. The lighter blue values on Figure B3 marks the data gaps from the measured time series.

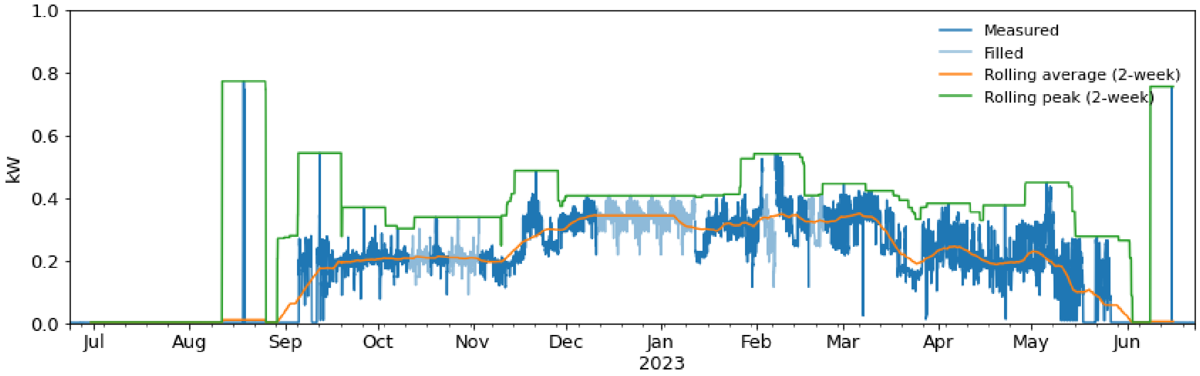


Figure B3: Energy consumption from the heat pump.

Hot water boiler

Figure B4 highlights the energy consumption from the hot water boiler. This device is connected to a solar thermal system that pre-heats the water to the extent that the boiler is not required for hot water production during the year's warmer months. From September, the hot water boiler operates a relatively peaky profile, even though it consumes a steady amount of energy when measured over a couple weeks. The lighter blue values on Figure B4 marks the data gaps from the measured time series.

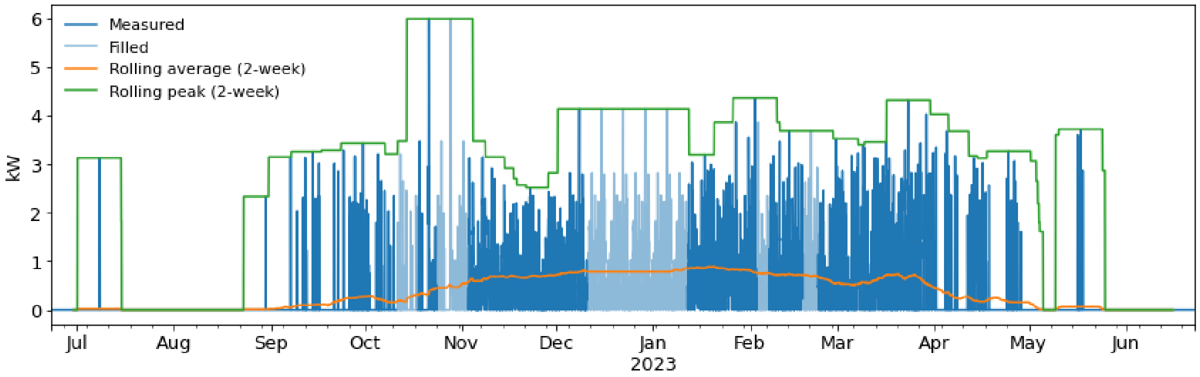


Figure B4: Energy consumption from the hot water boiler.

Radiator rings

Similarly, to the other heat related appliances, the radiators are used to a greater extent over the colder months of the year. Specifically, Figure B5 highlights how radiator 3 distributes less heat than the first two radiators. The lighter blue values on Figure B5 marks the data gaps from the measured time series.

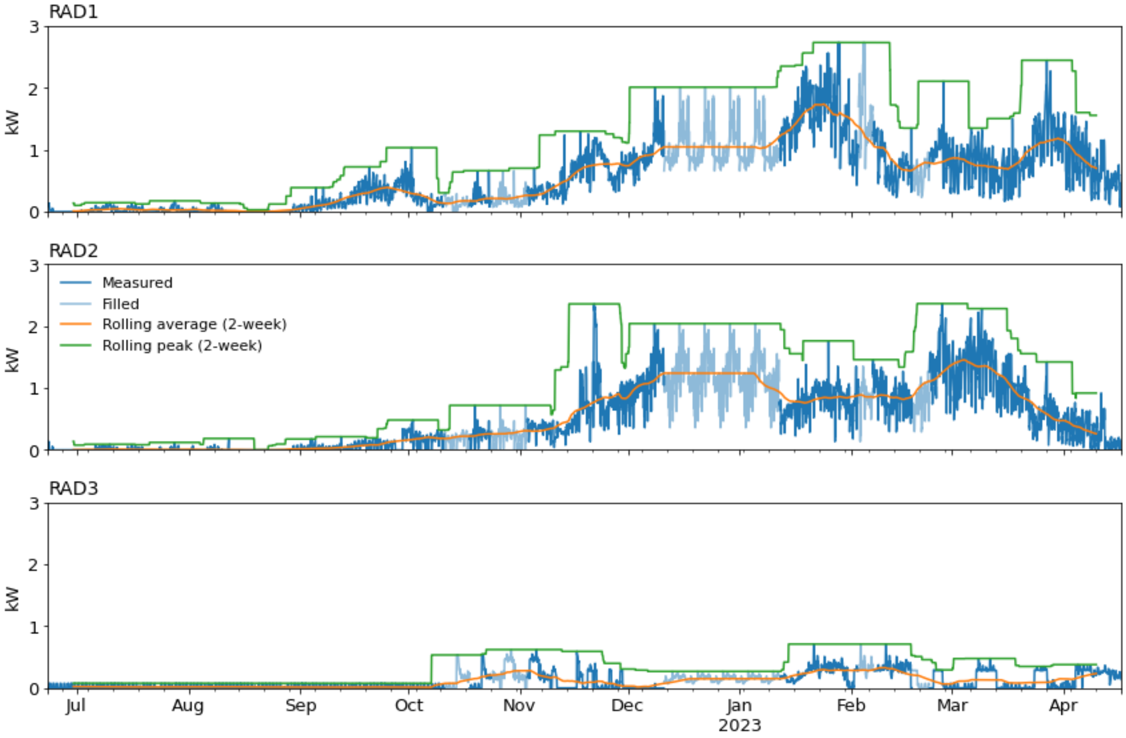


Figure B5: Energy consumption from the hot water boiler.

Solar panels

Solar energy production is presented in Figure B6. As expected, more electricity is generated from the panels during the months where the days are longer. Missing values were filled using irradiation data from SMHI, scaled to the system installed at the BRF.

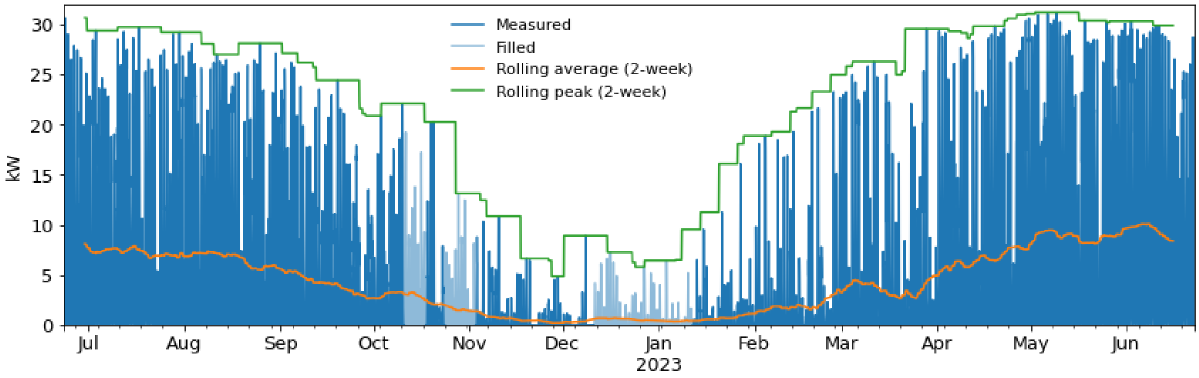


Figure B6: Solbyn solar energy production.

Flexible energy consumption

The Solbyn baseline energy consumption profile was be used to evaluate the control strategies. It consisted of the sum of the energy consumption from the appliances listed in this part of the appendix. Given the presence of the data gaps, it is considered that the most appropriate way to fill the missing values for the baseline profile is to adjust the energy consumption profile of the high-quality Skånska energi dataset. The blue line in Figure B7 highlights the Solbyn baseline energy consumption profile that was used to evaluate the control strategies.

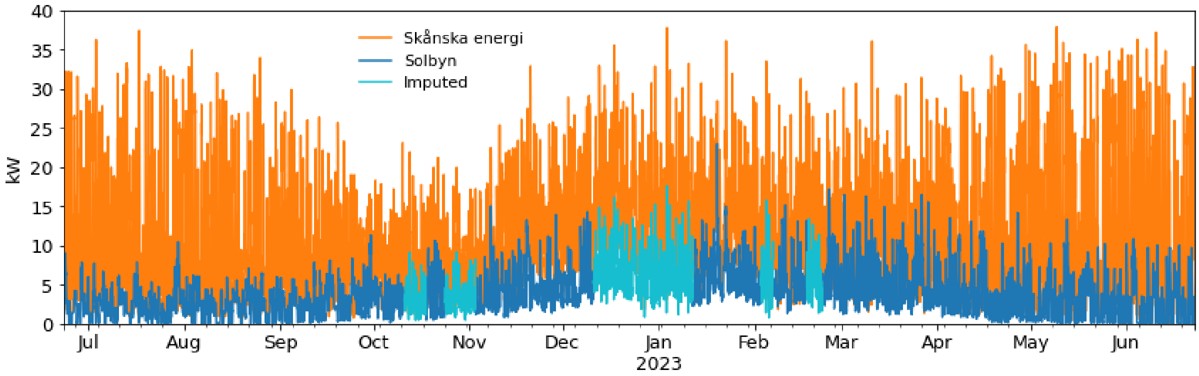


Figure B7: Solbyn baseline energy consumption profile in blue, against data from Skånska energi.

Specifically:

- The “Skånska energi” time-series corresponds to the data downloaded from the retailer’s website for Solbyn.
- The “Solbyn” time-series corresponds to the sum of the appliances whose energy consumption has been recorded and contains data gaps.
- The “Imputed” time-series corresponds to the Skånska energi profile, scaled to the “Solbyn” profile.

The scaling factor used for the “Imputed” timeseries is calculated using the one-week rolling averages (168 hours) of the other two timeseries. Specifically, the rolling average from the “Skånska energi” timeseries is scaled to fit into the gaps of the rolling average “Solbyn” timeseries. This is highlighted in Figure B8. Finally, the ratio between the two-rolling average timeseries is used to scale the “Skånska energi” timeseries directly into the “imputed” timeseries.

Figure B8: Solbyn baseline energy consumption profile in blue, against data from Skånska energi.

Appendix C – Demand curves and tariffs

The data gathered in Solbyn was important in setting the energy consumption baseline. This baseline forms the basis from which a control strategy can be implemented to both reduce power consumption and, by extension, consumer bills. Chapter 3 of the report refers to the following three profiles:

- Baseload –downloaded from Solbyn's account on the Skånska Energi web portal, this profile represents the energy consumption of the BRF's common facilities. It is used for filling in data gaps in the information collected from BRF's appliances.
- Flexible – the aggregate load of the all the BRF appliances, recorded directly from the BRF premises.
- Net Flexible – the remaining "flexible" load once the on-site solar PV generation has been netted off.

Solbyn's net flexible profile's load profile is presented in Figure C1 and its load duration curve is presented in Figure C2. These curves form the basis from which to evaluate the impact of the control strategies and represents the sum of the appliances presented in Appendix B. The value is expressed net of the solar power generated behind the meter on site.

After implementing the control strategies, the consumer can expect a reduction in the annual cost paid towards energy bills. In this regard, a cost saving is then calculated between the cost of the baseline load profile and the cost of the load profiles of the respective control strategies. This analysis is performed in Chapter 4 of the report.

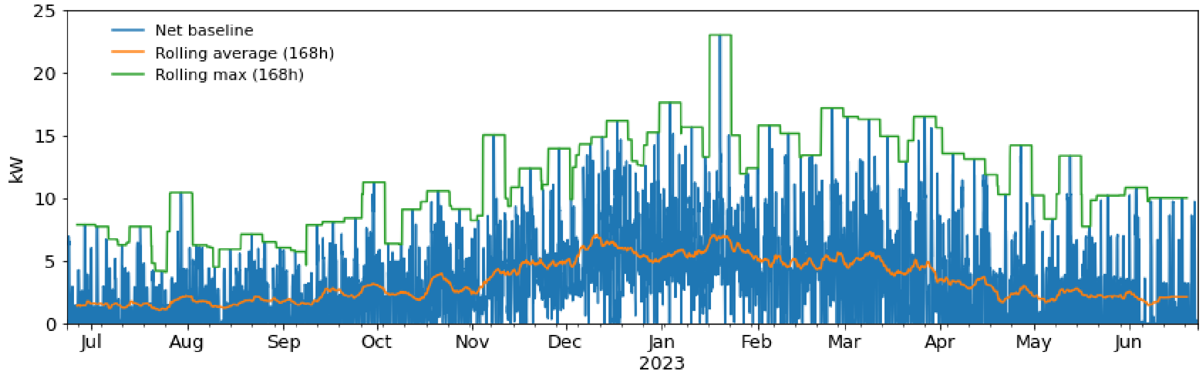


Figure C1: The flexible energy consumption profile.

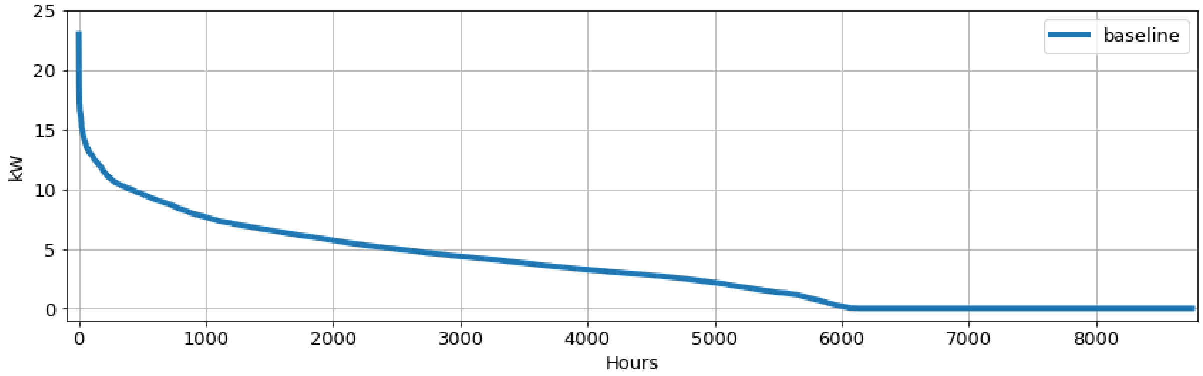


Figure C2: Flexible energy consumption profile load duration curve.

This appendix summarises the control strategies evaluated as part of this research project and compares their results against the baseline “flexible” profile presented in Figure C1. It should be noted that neither the heat pump nor the boiler are considered flexible appliances since controlling their operation would have an impact on the integrity of the service they provide, which affects the health, safety and wellbeing of the residents.

Rule based control – Limiting the number of fleet EVs charging at once

The premise behind this control strategy is to limit the number of fleet EVs that are permitted to charge simultaneously to three, all other EV charging requests within the fleet are placed in a queue. Under normal operating conditions, there are twelve charge points installed at Solbyn, wherein it is typical for fewer than five charge points to be active at once. The new load profile and load duration curve are presented in figures C3 and C4 below.

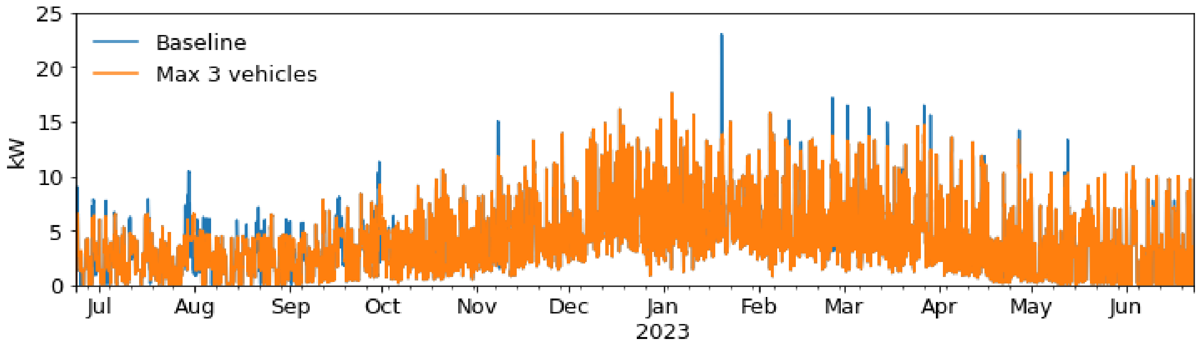


Figure C3: Flexible load profile, compared to the limited EV charging profile.

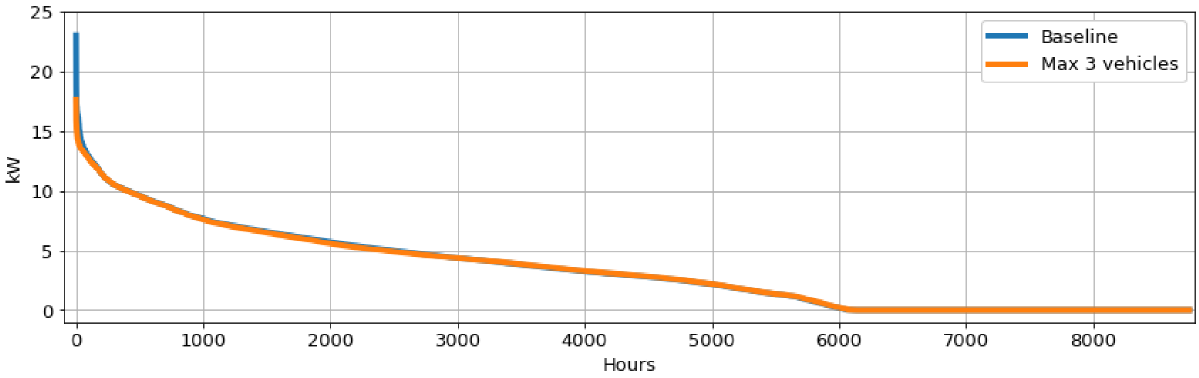


Figure C4: Flexible profile load duration curve, compared to that of the limited EV charging profile.

Under such operational conditions, the power peak would be reduced by 5 kW or approximately 23%. This information is presented in Table C1 below, wherein it is possible to see that the load factor has also increased by approximately 5 percentage points.

Table C1: Comparison of flexible load profile, before and after limiting EV charging.

Description	**Flexible**	**Max 3 EVs charging**
Annual consumption (MWh)	29.5	29.5
Average power demand (kW)	3.4	3.3
Peak power demand (kW)	23.0	17.6
Load factor (%)	14.6	19.0

Rule based control – Time based control of radiator rings

The premise behind this control strategy is to operate the radiators at 90% of their typical operations. In short, most energy savings would occur over winter at the time where they are needed the most. This reduces the practicality of such a control strategy. Additionally, it was found that the radiators tend to overcompensate when being turned on again. In other words, turning on the radiators will lead to a power spike that would not have otherwise occurred. The new load profile and load duration curve are presented in figures C5 and C6 below.

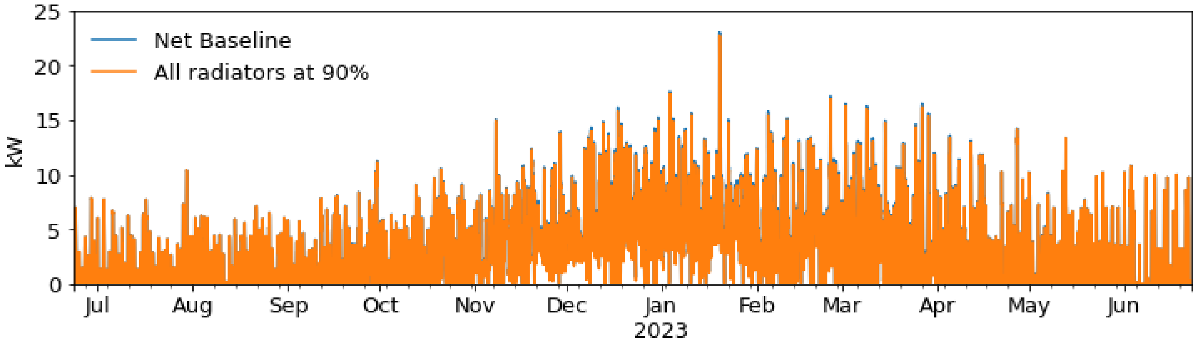


Figure C5: Flexible load profile, compared to the reduced radiator operation profile.

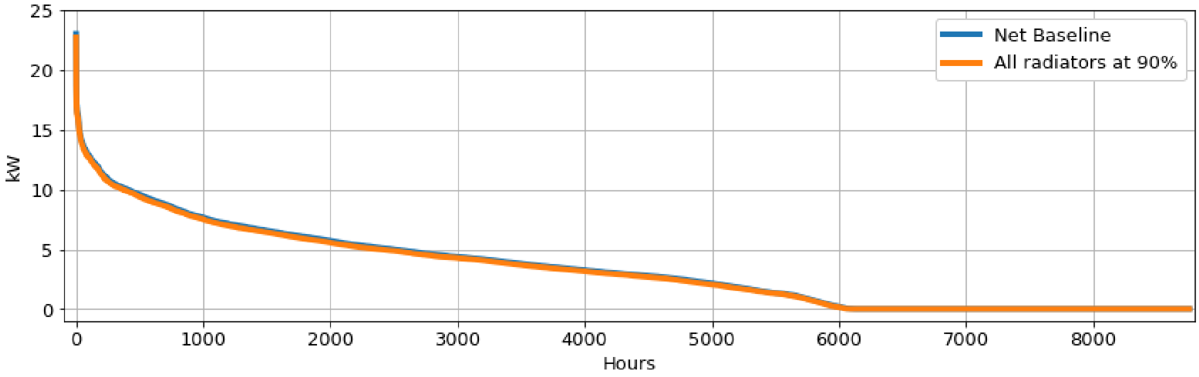


Figure C6: Flexible profile load duration curve, compared to the reduced radiator operation profile.

Under such operational conditions, 3% of energy consumption would be saved, with no significant impact on the flexible load's peak power consumption. This information is presented in Table C2 below, wherein it is possible to see that the load factor has not greatly changed.

Table C2: Comparison of flexible load profile, before and after restricting radiator operations.

Description	**Flexible**	**90% radiators**
Annual consumption (MWh)	29.5	28.7

Average power demand (kW)	3.4	3.3
Peak power demand (kW)	23.0	22.7
Load factor (%)	14.6	14.4

Real time control – Battery power guard

The premise behind this control strategy is to limit the power drawn from the grid by implementing a power-guard from the battery. In this control strategy the battery remains idle unless it is called upon to discharge power during peak times. The power-guard in this example is set at 15 kW. Therefore, the battery will discharge at any time when the power demand exceeds that value. The new load profile and load duration curve are presented in Figures C7 and C8 below.

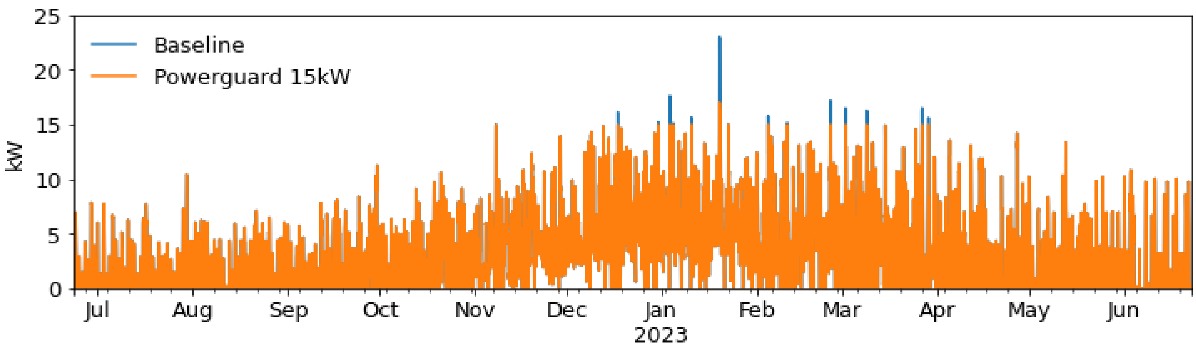


Figure C7: Flexible load profile, compared to the battery power-guard profile.

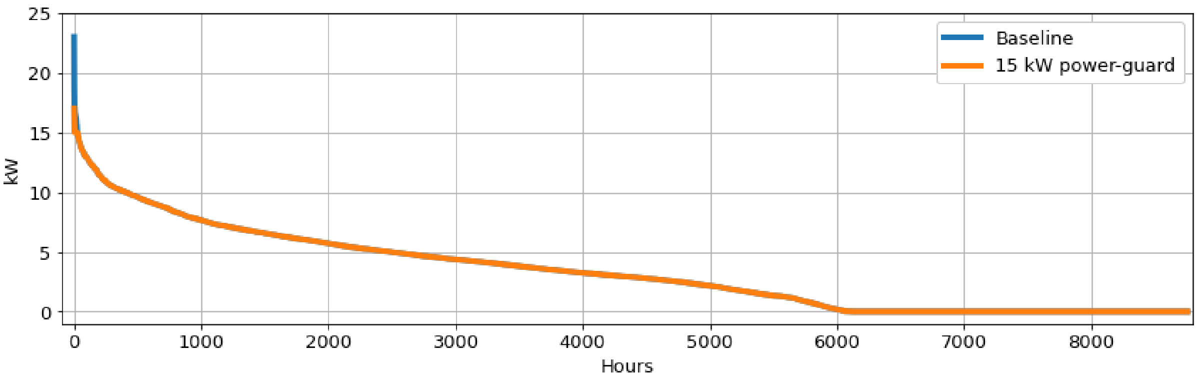


Figure C8: Flexible profile load duration curve, compared to the battery power-guard profile.

Under such operational conditions, the peak power consumption is reduced by 26%. This information is presented in Table C3 below, wherein it is possible to see that the load factor has correspondingly increased to almost 20%.

Table C3: Comparison of flexible load profile, before and after implementing the power-guard.

Description	**Flexible**	**Power-guard**
Annual consumption (MWh)	29.5	29.4
Average power demand (kW)	3.4	3.4
Peak power demand (kW)	23.0	17.0
Load factor (%)	14.6	19.8

This battery usage profile is not economically practical, since the battery is idle for most of the time, and not actually providing a service that would compensate for the original cost of the device. Figure C9 highlights the battery's state of charge throughout the year, and highlights how it has only been used on select occasions between the months of December and March.

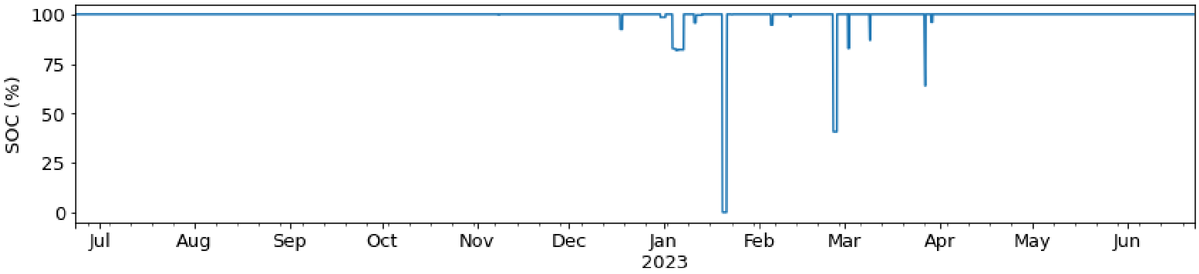


Figure C9: The battery state of charge under the power-guard only control strategy.

Real time control – Normal battery operation, charging from PV

The premise behind this control strategy is to maximise the opportunity for self-consumption of energy from the solar PV generation. The battery charges from excess solar PV generation and discharges at times where grid power would otherwise be consumed. It does not specifically target reducing power demand peaks. The new load profile and load duration curve are presented in figures C10 and C11 below.

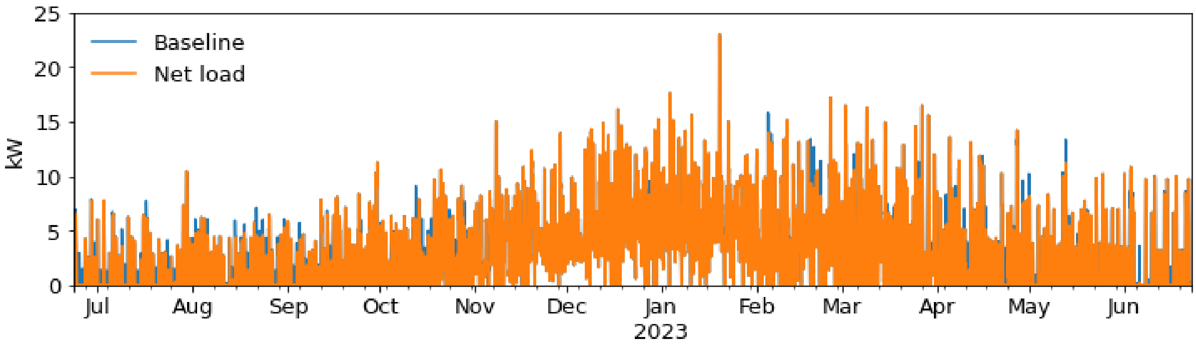


Figure C10: Flexible load profile, compared to the battery self-consumption profile.

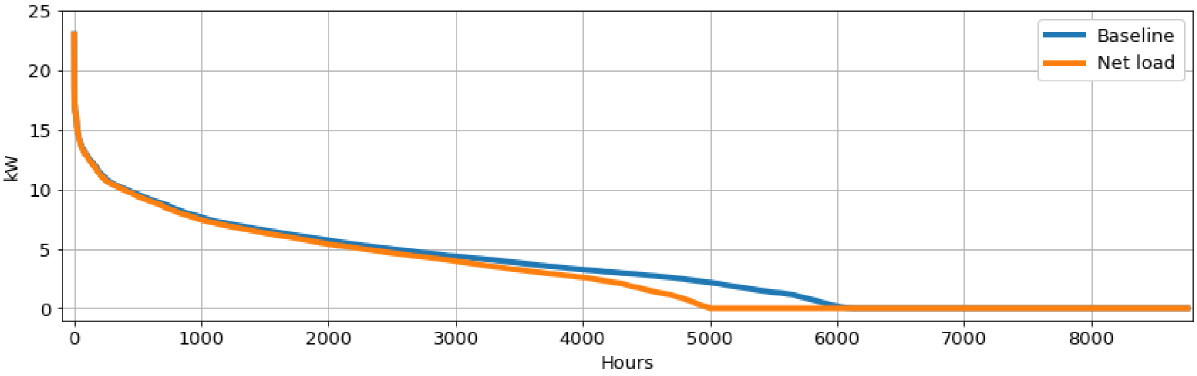


Figure C11: Flexible profile load duration curve, compared to the battery self-consumption profile.

Under such operational conditions, the energy consumption is reduced by 13%. This information is presented in Table C4 below, wherein it is possible to see that the load factor has decreased, since the battery is unable to reduce the peak load.

Table C4: Comparison of flexible load profile, before and after battery self-consumption.

Description	**Flexible**	**Battery**
Annual consumption (MWh)	29.5	25.6
Average power demand (kW)	3.4	2.9
Peak power demand (kW)	23.0	23.0
Load factor (%)	14.6	12.7

Real time control – Normal battery operation, charging from PV with power-guard

The premise behind this control strategy is to limit the power drawn from the grid by implementing a power-guard from the battery, whilst also maximising the opportunity for self-consumption of energy from the solar PV generation. The power-guard threshold depends on the load profile characteristics as well as the nominal battery capacity. In this case, the battery is rated at 6 kW and 15 kWh and the load of the net flexible profile is 23 kW. The power guard is therefore set to activate when the demand exceeds 17 kW. The new load profile and load duration curve are presented in figures C12 and C13 below.

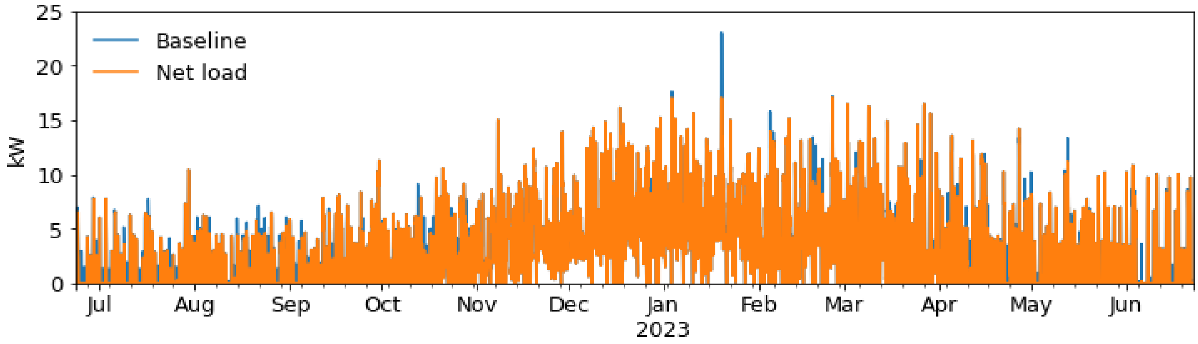


Figure C12: Flexible load profile, compared to the battery power-guard profile.

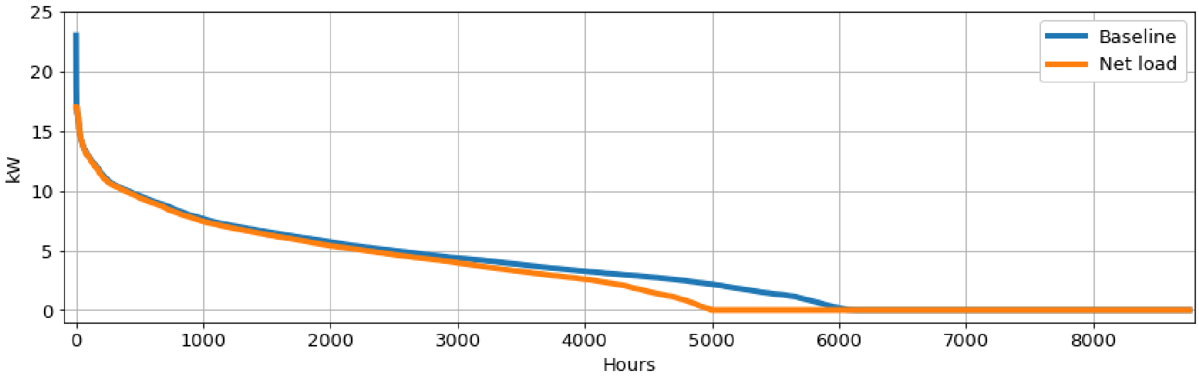


Figure C13: Flexible profile load duration curve, compared to the battery power-guard profile.

Under such operational conditions, the battery is capable of increasing energy self-consumption by almost 4 MWh. In other words, the battery's operation reduced the energy consumed from the grid by 13%. With the peak load also reduced, the load factor increases by almost three percentage points. This information is present in Table C5 below.

Table C5: Comparison of flexible load profile, before and after implementing the battery power-guard.

Description	**Flexible**	**Battery Flex**
Annual consumption (MWh)	29.5	25.6
Average power demand (kW)	3.4	2.9
Peak power demand (kW)	23.0	17.0
Load factor (%)	14.6	17.2

Hybrid control – Rule based EV charging control, with battery power-guard charging from PV

The premise of this strategy is to implement a hybrid control based on all the research strategies which minimises both the energy and the peak power consumption. This hybrid strategy therefore combines the two approaches:

- A maximum of three EVs are permitted to charge at once, all other EV charging requests within the fleet are placed in a queue,
- A grid power guard limit of 12.5 kW is implemented such that the battery provides all power requirements above that threshold.

The new load profile and load duration curve are presented in figures C14 and C15 below.

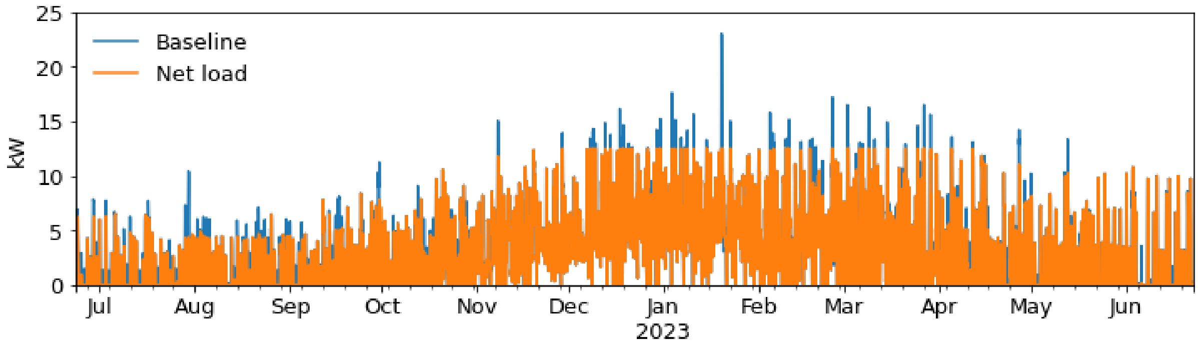


Figure C14: Flexible load profile, compared to the battery power-guard profile.

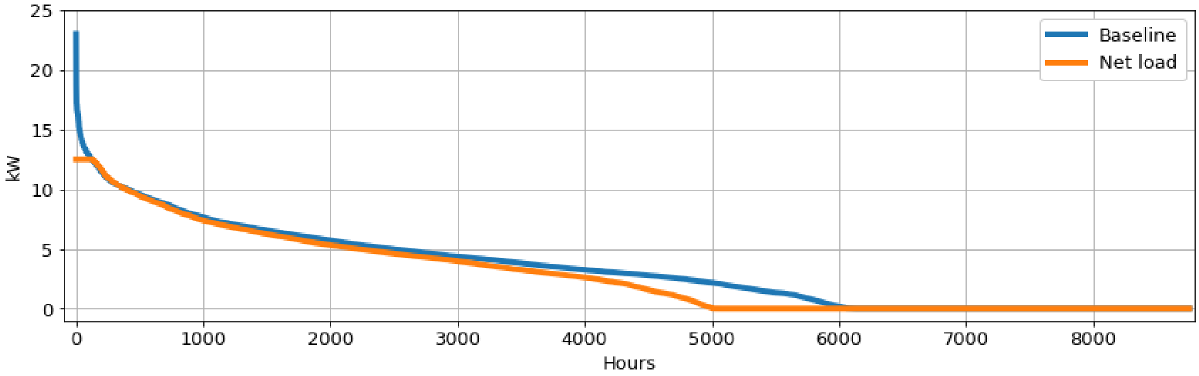


Figure C15: Flexible profile load duration curve, compared to the battery power-guard profile.

Under such operational conditions, the battery is capable of increasing energy self-consumption by almost 4 MWh annually and the peak power demand by 10.5 kW. This has the effect of increasing the load factor by nine percentage points. This information is present in Table C6 below.

Table C6: Comparison of flexible load profile, before and after implementing the battery power-guard.

Description	Flexible	Hybrid
Annual consumption (MWh)	29.5	25.4
Average power demand (kW)	3.4	2.9
Peak power demand (kW)	23.0	12.5
Load factor (%)	14.6	23.2

Tariff - Baseload

The results for the single energy- and power tariff are extended in this section for the baseload. 83 energy tariffs have been analysed from the different price areas in Sweden, 4 from SE1, 6 from SE2, 47 from SE3 and 26 from SE4. Figure C16 below shows the annual cost for the baseload profile.

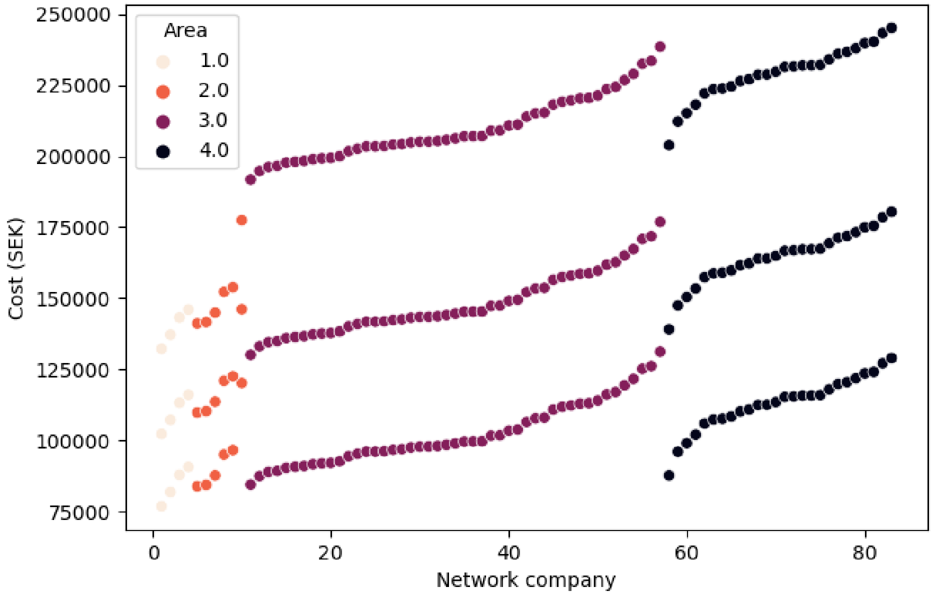


Figure C16: Annual cost of energy tariffs for the baseload profile from 2020-2022 in SE1-4.

In the Figure C16 above the years 2020, 2021 and 2022 are highlighted. The annual cost varies widely based on the price area. The mean annual cost is presented in Table C7.

Table C7: Mean annual cost of electricity for energy tariffs.

Year	SE1 (SEK)	SE2 (SEK)	SE3 (SEK)	SE4 (SEK)
2020	83923	94229	102031	112510
2021	109298	120160	147655	163886
2022	139234	151429	209258	228559

8 power tariffs have been analysed from the different price areas in Sweden, 1 from SE1, 1 from SE2, 5 from SE3 and 1 from SE4. Figure C17 below shows the annual cost for the baseload profile.

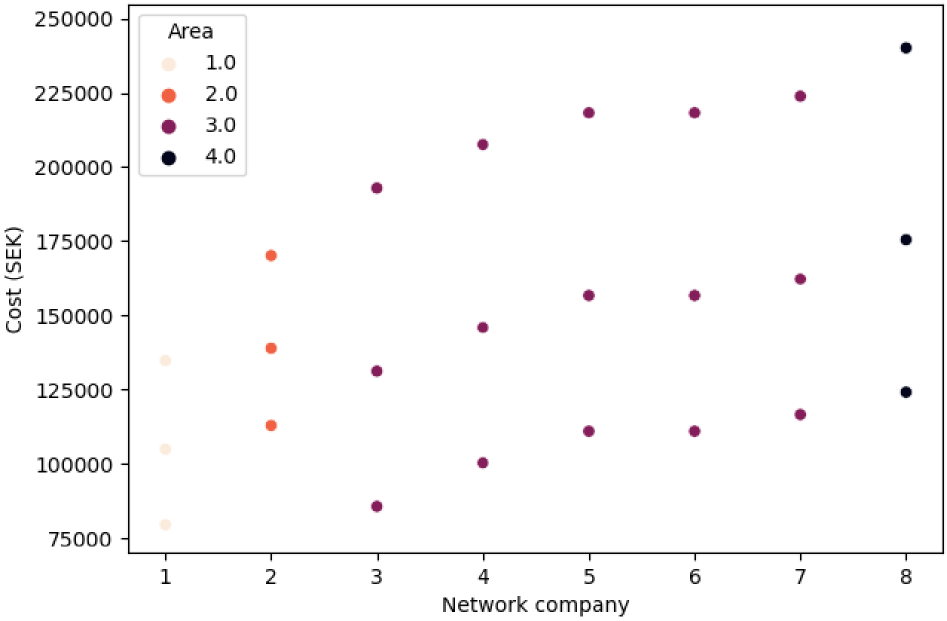


Figure C17: Annual cost of power tariffs for the baseload profile from 2020-2022 in SE1-4.

In the Figure C17 above the years 2020, 2021 and 2022 are highlighted. The annual cost varies based on the price area. The mean annual cost is presented in Table C8.

Table C8: Mean annual cost of electricity for power tariffs.

Year	**SE1 (SEK)**	**SE2 (SEK)**	**SE3 (SEK)**	**SE4 (SEK)**
2020	79537	112995	104957	124106
2021	104912	138925	150582	175482
2022	134848	170195	212184	240155

Tariff - Flexible load

The Figures below illustrate the annual cost for baseline flexible load profile “Net Flex”.

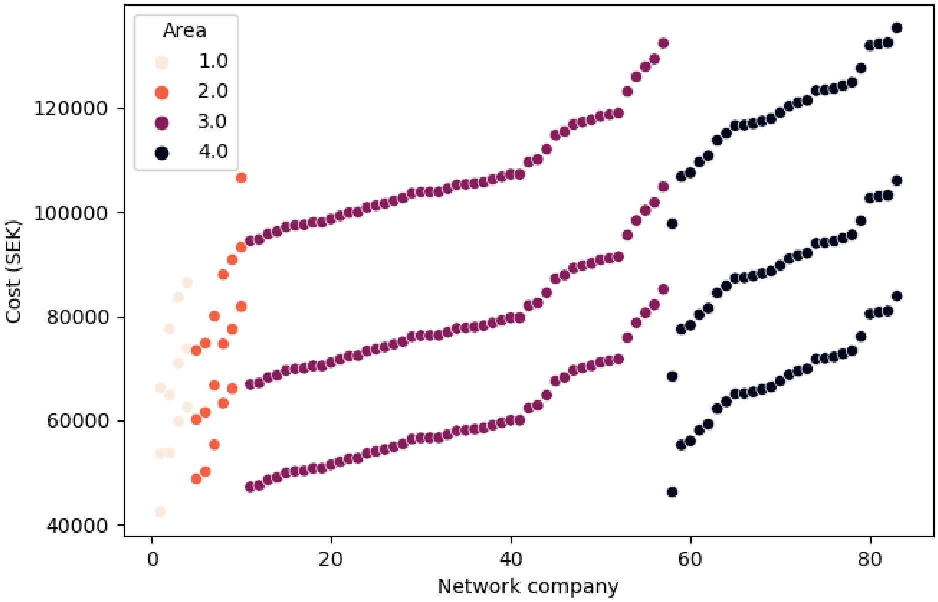


Figure C18: Annual cost of energy tariffs for baseline from 2020-2022 in SE1-4.

In the Figure C18 above the years 2020, 2021 and 2022 are highlighted. The annual cost varies widely based on the price area. The mean annual cost is presented in Table C9.

Table C9: Mean annual cost of electricity for energy tariffs.

Year	**SE1 (SEK)**	**SE2 (SEK)**	**SE3 (SEK)**	**SE4 (SEK)**
2020	54648	60917	60306	68023
2021	65799	72307	79943	90229
2022	78462	85587	107473	119488

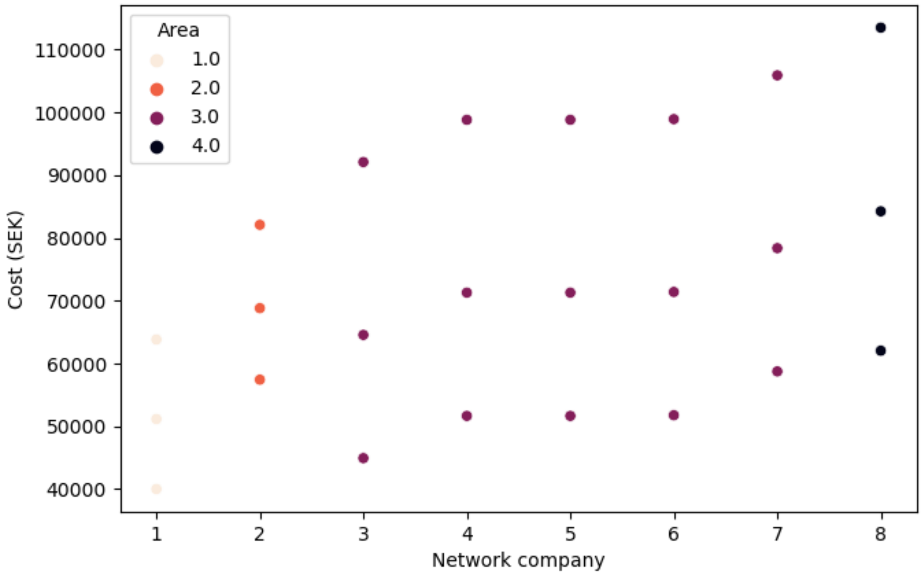


Figure C19: Annual cost of power tariffs for baseline from 2020-2022 in SE1-4.

In the Figure C19 above the years 2020, 2021 and 2022 are highlighted. The annual cost varies based on the price area. The mean annual cost is presented in Table C10.

Table C10: Mean annual cost of electricity for power tariffs.

Year	**SE1 (SEK)**	**SE2 (SEK)**	**SE3 (SEK)**	**SE4 (SEK)**
2020	40021	57442	51762	62056
2021	51173	68832	71399	84261
2022	63836	82111	98929	113521

Appendix D – Energy savings tool example

Two example load profiles are used to illustrate the spreadsheet calculations. Example 1 (blue) has no EV charging and a total annual energy consumption of 55000 kWh and a peak load of 10.65 kW. Example 2 (orange) includes EV charging (green), with an annual load of 49600 kWh and a peak load of 51.9 kW. The charging profile is then changed to charge over a longer time (red) to decrease kWp.

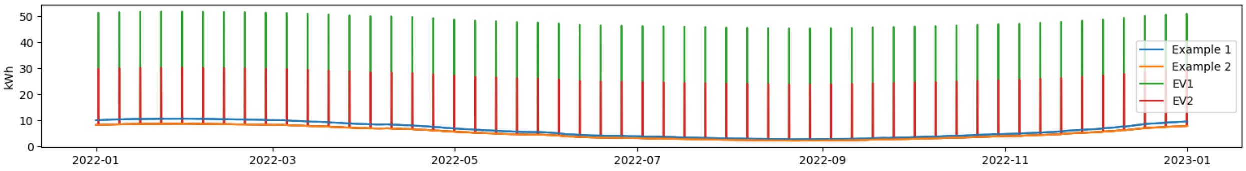
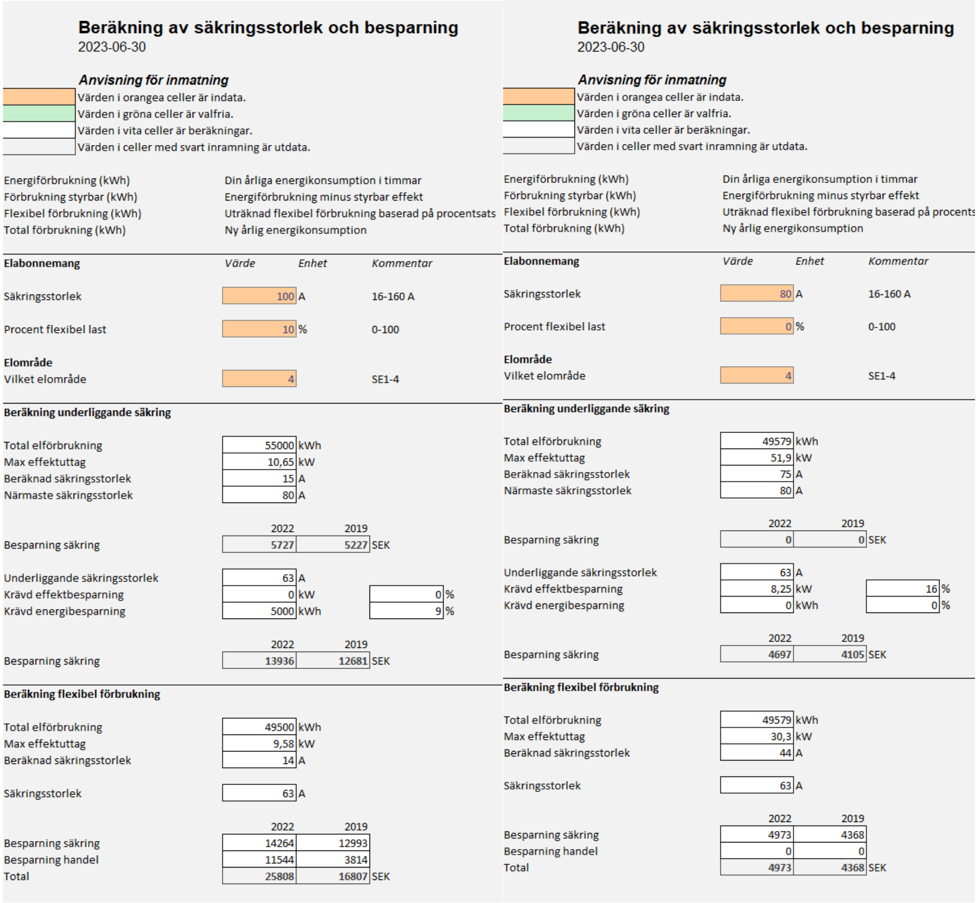


Figure D1: Example time-series for energy savings tool.



Beräkning av säkringsstorlek och besparning
2023-06-30

Anvisning för inmatning
🟧 Värden i orangea celler är indata.
🟩 Värden i gröna celler är valfria.
☐ Värden i vita celler är beräkningar.
☐ Värden i celler med svart inramning är utdata.

Energiförbrukning (kWh)	Din årliga energikonsumption i timmar
Förbrukning styrbar (kWh)	Energiförbrukning minus styrbar effekt
Flexibel förbrukning (kWh)	Uträknad flexibel förbrukning baserad på procentsats
Total förbrukning (kWh)	Ny årlig energikonsumption

Elabonnemang	*Värde*	*Enhet*	*Kommentar*
Säkringsstorlek	100	A	16-160 A
Procent flexibel last	10	%	0-100
Elområde			
Vilket elområde	4		SE1-4

Beräkning underliggande säkring

Total elförbrukning	55000	kWh		
Max effektuttag	10,65	kW		
Beräknad säkringsstorlek	15	A		
Närmaste säkringsstorlek	80	A		
	2022		2019	
Besparning säkring	5727		5227	SEK
Underliggande säkringsstorlek	63	A		
Krävd effektbesparning	0	kW	0	%
Krävd energibesparning	5000	kWh	9	%
	2022		2019	
Besparning säkring	13936		12681	SEK

Beräkning flexibel förbrukning

Total elförbrukning	49500	kWh		
Max effektuttag	9,58	kW		
Beräknad säkringsstorlek	14	A		
Säkringsstorlek	63	A		
	2022		2019	
Besparning säkring	14264		12993	
Besparning handel	11544		3814	
Total	25808		16807	SEK

Beräkning av säkringsstorlek och besparning
2023-06-30

Anvisning för inmatning
🟧 Värden i orangea celler är indata.
🟩 Värden i gröna celler är valfria.
☐ Värden i vita celler är beräkningar.
☐ Värden i celler med svart inramning är utdata.

Energiförbrukning (kWh)	Din årliga energikonsumption i timmar
Förbrukning styrbar (kWh)	Energiförbrukning minus styrbar effekt
Flexibel förbrukning (kWh)	Uträknad flexibel förbrukning baserad på procents
Total förbrukning (kWh)	Ny årlig energikonsumption

Elabonnemang	*Värde*	*Enhet*	*Kommentar*
Säkringsstorlek	80	A	16-160 A
Procent flexibel last	0	%	0-100
Elområde			
Vilket elområde	4		SE1-4

Beräkning underliggande säkring

Total elförbrukning	49579	kWh		
Max effektuttag	51,9	kW		
Beräknad säkringsstorlek	75	A		
Närmaste säkringsstorlek	80	A		
	2022		2019	
Besparning säkring	0		0	SEK
Underliggande säkringsstorlek	63	A		
Krävd effektbesparning	8,25	kW	16	%
Krävd energibesparning	0	kWh	0	%
	2022		2019	
Besparning säkring	4697		4105	SEK

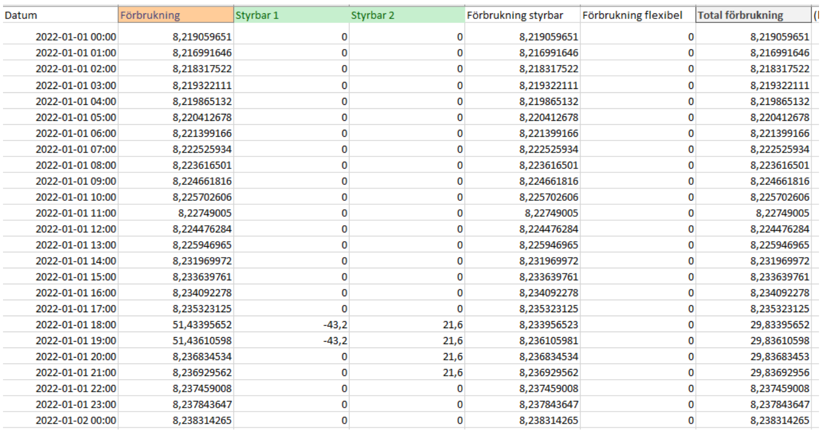
Beräkning flexibel förbrukning

Total elförbrukning	49579	kWh		
Max effektuttag	30,3	kW		
Beräknad säkringsstorlek	44	A		
Säkringsstorlek	63	A		
	2022		2019	
Besparning säkring	4973		4368	
Besparning handel	0		0	
Total	4973		4368	SEK

Figure D2: Example calculations of the energy savings tool, left without EVs, right including EVs.

Example 1 shows a multifamily housing building with a current fuse-size of 100 A and an assumed flexible load of 10% in SE4. The total annual load, peak power and maximum drawn current from the grid is calculated. The total consumption and peak power determine the fuse subscription level. In Example 1 the household was oversubscribed at 100 A, fitting the 80 A level of 80000 kWh, 56 kWp. By changing subscription level, they can save 5-6kSEK. Additionally, a calculation is made to determine how much total energy and power reduction is required to reduce the subscription further. In this case, a 5000 kWh reduction is required to reach 63 A. The new annual payment would then be for a load of 50000 kWh, matching the tariff 63 A, 50000 kWh, 44 kWp. For an assumed flexible load of 10% the new total consumption is calculated and both the savings from the lowered fuse subscription and traded electricity for price area 4 are calculated. The savings for lowering the fuse size from 100 A to 63 A was 13-14 kSEK, adding the savings from the purchased electricity for the flexible consumption case the savings were 17-26 kSEK.

Example 2 shows a multifamily housing building with a current fuse-size of 80 A and an assumed flexible load of 0% in SE4. The total annual load, peak power and maximum drawn current from the grid is calculated. In Example 2 the household has two EVs with a 43.2 kWh battery each, average sizing from [12] charging with 21.6 kW, highest slow-rate household chargers are <22 kW [12], for two hours once every week, 52 times per year. The limitation in this example is the kWp of 74.9 A drawn from the grid. The first part of the calculation determines that the fuse is correctly sized to the energy profile and that the power rating is the limiting factor for a lower subscription of 63 A (8.25 kW reduction needed). This is then achieved by using the columns 'Styrbar 1' and 'Styrbar 2'.



Datum	Förbrukning	Styrbar 1	Styrbar 2	Förbrukning styrbar	Förbrukning flexibel	Total förbrukning
2022-01-01 00:00	8,219059651	0	0	8,219059651	0	8,219059651
2022-01-01 01:00	8,216991646	0	0	8,216991646	0	8,216991646
2022-01-01 02:00	8,218317522	0	0	8,218317522	0	8,218317522
2022-01-01 03:00	8,219322111	0	0	8,219322111	0	8,219322111
2022-01-01 04:00	8,219865132	0	0	8,219865132	0	8,219865132
2022-01-01 05:00	8,220412678	0	0	8,220412678	0	8,220412678
2022-01-01 06:00	8,221399166	0	0	8,221399166	0	8,221399166
2022-01-01 07:00	8,222525934	0	0	8,222525934	0	8,222525934
2022-01-01 08:00	8,223616501	0	0	8,223616501	0	8,223616501
2022-01-01 09:00	8,224661816	0	0	8,224661816	0	8,224661816
2022-01-01 10:00	8,225702606	0	0	8,225702606	0	8,225702606
2022-01-01 11:00	8,22749005	0	0	8,22749005	0	8,22749005
2022-01-01 12:00	8,224476284	0	0	8,224476284	0	8,224476284
2022-01-01 13:00	8,225946965	0	0	8,225946965	0	8,225946965
2022-01-01 14:00	8,231969972	0	0	8,231969972	0	8,231969972
2022-01-01 15:00	8,233639761	0	0	8,233639761	0	8,233639761
2022-01-01 16:00	8,234092278	0	0	8,234092278	0	8,234092278
2022-01-01 17:00	8,235323125	0	0	8,235323125	0	8,235323125
2022-01-01 18:00	51,43395652	-43,2	21,6	8,233956523	0	29,83395652
2022-01-01 19:00	51,43610598	-43,2	21,6	8,236105981	0	29,83610598
2022-01-01 20:00	8,236834534	0	21,6	8,236834534	0	29,83683453
2022-01-01 21:00	8,236929562	0	21,6	8,236929562	0	29,83692956
2022-01-01 22:00	8,237459008	0	0	8,237459008	0	8,237459008
2022-01-01 23:00	8,237843647	0	0	8,237843647	0	8,237843647
2022-01-02 00:00	8,238314265	0	0	8,238314265	0	8,238314265

Figure D3: Illustration of how to utilize the 'Styrbar 1' and 'Styrbar 2' columns.

First the EV load is removed. This is done to accurately calculate the flexible load. E.g. if the assumed flexible load is 10%, that is a percentage of the annual load minus the EV load. The old charging pattern is inputted into 'Styrbar 1' and the new charging pattern into 'Styrbar 2'. In this case there were two EV chargers with 43.2 kWh batteries charging two hours at a rate of 21.6 kW. This was then distributed over four hours into a rate of 10.8 kW each. For an assumed additional flexible load of 0% the new total consumption is calculated. Since only a rescheduling/load shifting of the EVs were required only the savings for the lowered subscription are calculated. The savings for lowering the fuse size from 80 A to 63 A was 4-5 kSEK. Fuse sizes for the calculations are described in Table D1.

Table D1: Fuse sizings.

Size (A)	Annual consumption (kWh)	kWp
16	2000	11
16	5000	11
20	10 000	14
20	20 000	14
25	20 000	17
25	30 000	17
35	30 000	24
63	50 000	44
80	80 000	56
100	100 000	70
125	125 000	87
160	190 000	111

Runt 35 procent av all energi i Sverige används i bebyggelsen. I forskningsprogrammet E2B2 arbetar forskare och samhällsaktörer tillsammans för att ta fram kunskap och metoder för att effektivisera energianvändningen och utveckla byggandet och boendet i samhället. I den här rapporten kan du läsa om ett av projekten som ingår i programmet.

E2B2 är Energimyndighetens program där IQ Samhällsbyggnad är koordinator.
Läs mer på www.E2B2.se.