D3.4 Interoperability of holistic energy systems in Espoo

30/09/2022

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Deliverable administration

No & name	D3.4 Interoperability of holistic energy systems in Espoo				
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Description of the related task and the deliverable. Extract from DoA	**D3.4 is a final report compiling block and district level energy system solutions implemented in Lighthouse City of Espoo. The deliverable is an analytical cross-cutting report of outcomes from tasks T3.2, T3.3, and T3.5. (R, PU, M36)** **T3.2 Energy positive blocks (ESP, VTT, SIE, CIT, ADV) [M1-M60]** This task demonstrates solutions and actions for a holistic and sustainable energy transformation towards energy positive blocks and districts, and a carbon neutral Espoo 2030. Block specific and macro level subtasks include: • Subtask 3.2.1 RES integration in Energy Positive Lippulaiva blocks (CIT, VTT, ADV) [M1-M36] • Subtask 3.2.2 Smart energy solutions for self-sufficiency in the Leppävaara center (SIE, VTT, (SELLO)) [M1-M36] • Subtask 3.2.3 City Planning for Positive Energy blocks (ESP) [M1-M60] • Subtask 3.2.4 City scale smart heating and thermal demand response (VTT, ESP) [M1-M36] **T3.3 ICT and interoperability (SIE, VTT, ESP, KONE) [M1-M36]** This task includes solutions for smart city, ICT based energy management. Work is divided into following subtasks: • Subtask 3.3.1 Virtual Power Plant for optimized RES energy use (SIE, VTT, ESP, KONE) [M1-M36] • Subtask 3.3.2 Smart energy services (ESP, SIE) [M1-M60] • Subtask 3.3.3 Smart Building Energy Management (KONE, SIE) [M1-M36] **T3.5 Planning of Energy Positive Districts (ESP, VTT) [M1-M60]** The task develops urban planning methodologies for smart city development including: Subtask 3.5.1 Energy Positive District Planning (ESP) [M1-M60] • CityGML as a tool for energy positive block development: Starting 2019, The city offers an open and public 3D City model. The task implements the MODER tool using Apros simulator and City GML integration, for assessing the potential for energy positive blocks in Espoo. (VTT, Espoo; Action E17-2) • Co-creation for smart city development. Co-creation models for smart city planning are developed as a collaboration between industry, SMEs, citizens and other stakeholders. (ESP, (stakeholders); Action E22-1) • FINNOO area: replication planning (ESP; Action 20-1). The results of Actions E20-1 and E22-1 are reported in deliverable D3.3				

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Participants	ESP, VTT, KONE, SIE, CIT, ADV,		
Comments	• Deliverable draft was reviewed by Irene Müller (LPZ), Jani Tartia and Elina Wanne (ESP)		
V	Date	Authors	Description
0.1	04/2022	VTT	First draft
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0.9	09/2022	WP leader	Deliverable checked by WP leader and released to the Coordinator and the Quality Manager for quality check and subsequent submission to the EC.
1	30.09.2022	VTT	Coordinator submits the deliverable to the EC

Dissemination level		
PU	Public	x
CO	Confidential, only for members of the consortium (including the Commission Services)	

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About SPARCS

Sustainable energy Positive & zero cARbon CommunitieS demonstrates and validates technically and socioeconomically viable and replicable, innovative solutions for rolling out smart, integrated positive energy systems for the transition to a citizen centred zero carbon & resource efficient economy. SPARCS facilitates the participation of buildings to the energy market enabling new services and a virtual power plant concept, creating VirtualPositiveEnergy communities as energy democratic playground (positive energy districts can exchange energy with energy entities located outside the district). Seven cities will demonstrate 100+ actions turning buildings, blocks, and districts into energy prosumers. Impacts span economic growth, improved quality of life, and environmental benefits towards the EC policy framework for climate and energy, the SET plan and UN Sustainable Development goals. SPARCS co-creation brings together citizens, companies, research organizations, city planning and decision making entities, transforming cities to carbon-free inclusive communities. Lighthouse cities Espoo (FI) and Leipzig (DE) implement large demonstrations. Fellow cities Reykjavik (IS), Maia (PT), Lviv (UA), Kifissia (EL) and Kladno (CZ) prepare replication with hands-on feasibility studies. SPARCS identifies bankable actions to accelerate market uptake, pioneers innovative, exploitable governance and business models boosting the transformation processes, joint procurement procedures and citizen engaging mechanisms in an overarching city planning instrument toward the bold City Vision 2050. SPARCS engages 30 partners from 8 EU Member States (FI, DE, PT, CY, EL, BE, CZ, IT) and 2 non-EU countries (UA, IS), representing key stakeholders within the value chain of urban challenges and smart, sustainable cities bringing together three distinct but also overlapping knowledge areas: (i) City Energy Systems, (ii) ICT and Interoperability, (iii) Business Innovation and Market Knowledge.

Partners

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SPARCS

Executive Summary

This report addresses from energy point of view all of the demonstration actions that are realised by SPARCS in the city of Espoo, Finland by the end of the third project year. At beginning, an overall summary of the Lighthouse demonstrations in Espoo is presented, and then continue summarising the details in the demonstration areas. The demonstration actions cover broadly various low carbon improvements of urban area development, including buildings, energy systems, transportation, urban planning and citizen involvement. Some of these aspects are covered in other parallel deliverables, e.g. D3.3, however from another perspective.

Espoo city structure has five large district centres, and our demonstration areas focus on two of these centres in Leppävaara and Espoonlahti districts. Sello area at the centre of Leppävaara district is an existing urban area, where demonstration actions focus on improving (already high) energy efficiency of the existing urban infrastructure, although there are currently massive construction sites improving the public transportation connection. Lippulaiva block at the centre of Espoonlahti district is a new block that is currently under construction, hence, offering us a potential to test and demonstrate energy positive block solutions in new buildings. The most important part of it, Lippulaiva commercial center, has been completed and started commercial operations in March 31, 2022. In addition to more practical demonstrations, we have a 3rd demo site concentrating on urban planning in the Kera area, with the high ambition level for sustainable and smart district development. And finally, SPARCS also studies macro level demonstration actions in the city of Espoo.

This report describes the results obtained so far from the energy point of view and provides the summary of the progress towards the following monitoring phase.

Demo Lippulaiva

The construction of the new Lippulaiva shopping center has been completed and the mall operates since March 31st, 2022. Its heating and cooling demand is mainly covered with an on-site geothermal heat pump system (among the largest of this kind in Europe). Electricity demand is covered with PV panels (roof and façade) and certified renewable electricity. The energy consumption and production are smartly controlled and Lippulaiva participates in the Nordpool's reserve market. The idea is to follow a day-ahead market price for electricity and participate in reserve market with battery storage. Simultaneously, the smart electricity control service should cut peak loads and gain savings in electricity costs.

Demo Sello

Smart energy solutions for self-sufficiency in the Leppävaara Sello center are in the focus. Sello's thermal energy processes are modelled to understand the potential increased energy efficiency, self-sufficiency, and thermal flexibility. The potential is realized by providing the thermal flexibility to local district heating company (Fortum). Increasing the self-sufficiency through deep heat geothermal well is evaluated using the Power System Simulator PSS.

The goal of the activities was to create a messaging interface between the Siemens building management system (BMS) and Fortum heat plant automation, send the

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required flexibility calls via the new interface and adjust the heating demand based on the calls. The solution is now implemented as a pilot project in the Shopping centre Sello. The created solution includes flexibility forecast and the actual demand response request sent by Fortum. The required actions are made by Siemens BMS, which adjusts the required flexibility based on the consumption at the time.

City planning

City planning for positive energy blocks is about the development and the planning of positive energy blocks. Mainly the focus was on exploring the possibilities to utilize tools (such as the Espoo's 3D city model) in the development and the planning of new areas, but also on how to find energy infrastructure solutions and develop guidelines that enhance the uptake of such solutions.

The City of Espoo also examined different opportunities offered by energy community legislation and new cost-efficient renewable energy generation and distribution technologies. The work gives an overview of the existing regulations on energy communities and addresses the potential to form an energy community in the developing Kera district. Also assessed were possible business models for the electricity, heating, cooling and fuel sectors in the context of the Kera district. Current and new business models were mapped, and the suitability of different models to the Kera area was explained.

Smart and sustainable district heating holds great potential to reduce emissions. Artificial intelligence- driven district heating together with demand side management (DSM) play and important role in the climate challenge and help shaving thermal peak loads and save emissions. The conducted study on a sample of buildings provided quantification of energy savings and avoided emissions.

ICT demonstrations

Virtual Power Plants are a critical element in transition towards decentralized energy systems and are enabled by digitalization. The energy sector is expected to benefit from blockchain technology. Objective of one of the activities in SPARCS is to enable sector coupling and increase the interoperability, monitoring and control of various energy systems by ICT between smart buildings, smart grid and district heating and cooling systems, EV charging infrastructure, and the allocation of open data.

Models for building automation data were researched in Sello commercial center to allow creating more intelligent, scalable, and interoperable programs. The first architecture BIM model was done from drawings of building, later a 3D laser scanned point cloud was created from selected technical rooms in Sello. The point cloud was then connected to the Architecture BIM Model.

In-depth data analysis was done for Electricity, Water and Heating meters. The three targets "flexibility down", "flexibility up" and "instant power reference" are now forecasted with a prediction horizon of 24 hours. These forecasts can be used as part of Sello's energy optimization or in virtual power plant (VPP).

The newly created Virtual Twin for Sello makes it possible to visualize selected energy or heating, ventilation, and air conditioning (HVAC) near real-time or historic data by 3D building information model (BIM) based virtual model. This helps to find and visually

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locate those Sello's heating, cooling and air conditioning zones that are not working as energy efficiently as some other Sello zones.

Smart energy services

Activities about Smart Building Energy Management demonstrated how domain knowledge and real-time monitoring of elevators, escalators and people flow can be employed for smarter decision making and demand response actions by the building energy management system. KONE has developed an algorithm that can forecast the short-term, high-resolution power demand of selected elevators. In Sello, the communication between the KONE solution and Siemens platform was established, after which an air-handling unit was set to be controlled based on an algorithm interpreting the received elevator power demand forecast.

PED planning

This work aimed to clarify how CityGML could support low carbon urban planning and block/district level energy analysis. To carry out block-level 12-month simulation, a simplified building energy consumption model implemented in Apros software was adapted as python scripts to be run from QGIS python console to visualize the results on map. With this approach the building models can be used to estimate the aggregated impact of energy efficiency improvement measures, e.g. replacement of energy efficient windows or rooftop PV installations in the building stock in the city. A visualization of results in terms of the indicators for electricity was implemented for buildings using color-coding in QGIS software.

To create new approaches for smart city planning that could also take into consideration PEDs, the City of Espoo conducts a process to create a "co-creation model" for sustainable and smart urban areas. Developing such a smart city area as a whole required new tools, practices and processes of co-creation and dialogue to connect the different stakeholders, builders, investors, policy makers, organizations and citizens together in the city planning. This process covers the whole life cycle of the area from the initial planning to the in-depth design, construction, and use and operation phases.

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1 Introduction

1.1 Purpose and target group

Within SPARCS, the city of Espoo is developing a customized approach concerning the implementation of integrated concrete solutions promoting city's transition towards a sustainable urban ecosystem, focusing at first on Positive Energy Districts (PEDs)/Blocks. The aim is to prove that the urban energy transformation of a city into a carbon neutral urban community is socially and economically viable.

This deliverable is a final report compiling block and district level energy system solutions implemented in the Lighthouse City of Espoo. The deliverable is an analytical cross-cutting report of outcomes from tasks T3.2, T3.3, and T3.5 (due in M36). It has some thematic overlapping with the deliverable D3.3 (Implemented demonstrations of solutions for energy positive blocks in Espoo) but contains more technical details and focuses on energy related aspects.

The interventions and actions presented in this deliverable are related to various aspects of Positive Energy Blocks: buildings, energy, transportation, ICT, people involvement and urban planning. Each demonstration action has a detailed work plan, targeted outcome, and defined roles and responsibilities. Besides detailed implementation plans, the project also includes preparation plans for the monitoring phase, which is following the demonstration phase after M36.

The demonstration actions presented in this report follow the task structure of WP3:

- A summary of the Espoo lighthouse actions activities in section 2, following the work done in T3.1 Local coordination in Espoo.
- Energy positive blocks demonstrations (task 3.2) in section 3, including:
    - Lippulaiva site in section 3.2,
    - Leppävaara site in 3.3,
    - Kera urban planning actions in section 3.4, and
    - Macro level energy related action in section 3.5.
- ICT and interoperability demonstrations (task 3.3) in section 4.
- The planning of energy positive districts (task 3.5) in Espoo in section 5.

The following actions are addressed in other parallel deliverables:

- E-mobility integration activities (task 3.4) in D3.5.
- The community engagement activities (task 3.6) in D3.6.
- Air quality (task 3.7) in D3.3.
- Smart business models (task 3.8) in D3.6.
- Replication and exploitation preparation (task 3.9) in D3.3.

This report is primarily targeted for organisations working in the SPARCS and collaborative Smart City stakeholder groups. It can also provide insights to other lighthouse projects and cities, and stakeholders; as well as for other cities starting to plan similar kind of smart city developments.

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1.2 Contributions of partners

The following Table 1 depicts the main contributions from partners in this deliverable.

Table 1. Contributions of partners.

Partner	Contributions
VTT	Editor of the deliverable. Content planning, allocation of writing responsibilities. Lead of section Executive summary and sections 3.5 and 6
ESP	Sections 1, 2, 3.1, 3.4, 4.3 and 5
CIT	Section 3.2
SIE	Sections 3.3, 4.1, and 4.2
KONE	Section 4.4
ADV	Action E1-1, E1-4, E1-5, and E1-6 in section 3.2

1.3 Relations to other activities

The following Table 2 depicts the main relationship of this this deliverable to other activities or deliverables within the SPARCS project.

Table 2. Relation to other activities in the project.

Deliverable / Milestone	Contributions
D3.3	D3.3 is developed further from D3.2, describing the implemented demonstrations of solutions for energy positive blocks in Espoo (due in M36).
M8	This deliverable supports for completion of the demonstration sites in Espoo by M30.
WP2	KPIs development initiated and supporting the monitoring of the actions. The KPI's have been identified, paving the way for impact assessment in work package 2 and supporting the preparation for the monitoring phase.
WP5	Project upscaling and replication in Light House Cities. Replication preparation and planning activities (T3.9) are strongly supported by WP5.
WP6	Knowledge change between other SCC1 projects and other networks and cross-horizontal collaboration activities. Contributions to recommendations building in T6.2.
WP8	Dissemination and communication of activities in Espoo.

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2 OVERVIEW OF LIGHTHOUSE DEMONSTRATIONS IN ESPOO

2.1 Introduction to activities in Espoo

One special characteristic of Espoo is its urban structure: instead of one city centre, Espoo has altogether five city centers that are like smaller cities within the city, providing all necessary services close to the people. In this project, two of the three demonstration areas in Espoo are located in these city centres: the Sello blocks in Leppävaara district, and the Lippulaiva blocks in Espoonlahti district. Both city centres are currently developing rapidly, as are new smaller districts, such as Kera, the third demonstration area in the project. Kera is actually part of Greater Leppävaara district.

With 56,000 residents Espoonlahti is the second largest of Espoo's multiple city centres. The area is partially redeveloped and at its heart locates the newly opened (March 2022) shopping centre Lippulaiva. SPARCS interventions for solutions for Positive Energy Blocks in Lippulaiva concentrate on on-site energy production and smart controlling solutions for both energy consumption and production. The shopping center hosts the largest geothermal heating and cooling energy plant in Europe for a commercial building. The regenerative geoenergy system by Adven, which is built under the shopping centre, is designed to cover 100% of the cooling demand and almost the entire heating demand of the shopping center and residential buildings nearby, leaving only a fraction of heat to be sourced from the district heating grid in case of prolonged cold weather. Additionally, renewable electricity is provided on-site with PV panels and an electric battery allows not only to store energy but also to participate in the reserve market. Lippulaiva achieved the LEED GOLD environmental certification and the Smart Building GOLD certification in spring 2022.

The Leppävaara district is the largest of the Espoo's five city centres. The demo area in Leppävaara is located around the Sello shopping centre and its block, which is a mixed-use space consisting of residential buildings, public services and entertainment. SPARCS interventions for smart energy solutions for self-sufficiency in the Leppävaara center focuses on increasing efficiency, flexibility and self-sufficiency through digital tools and through local thermal energy production. Sello's electricity needs are covered by renewable energy produced locally by PV in summer and in transitional months (750kW PV). During days with low solar irradiance, green electricity is provided by the centre's virtual power plant. The virtual power plant also utilizes a battery energy storage system connected to the Fingrid market for local flexibility. Controlled electric loads, such as lighting, HVAC and elevators support the total system balancing and increase the total flexible capacity that can be sold to Fingrid's Frequency Containment Reserves. In turn, Sello's heating needs are covered via district heating. The district heating system leverages demand side management by utilizing the thermal mass of building structures, thus reducing peak loads and lowering both costs and emissions. These sustainable energy solutions allowed Sello to receive the LEED environmental rating system's platinum classification for its operations in 2015.

Kera is the city planning demonstration for positive energy blocks, located in the Leppävaara district. The Kera area is a deprived industrial area developed in the 1970s and it will now be reallocated for mostly residential use. Existing landowners include the retail group S-Ryhmä, currently one of the largest producers of renewable energy

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in Finland, and Nokia, with headquarters in immediate vicinity and strong support to the 5G based smart infrastructure development in Kera. SPARCS is developing and piloting new models for co-creation, energy communities and stakeholder engagement to bring residents in the new Kera district to the center of energy ecosystem, maximizing local production and encouraging prosumer models to enhance the utilization of distributed generation.

Solutions will be replicated in other sites around Espoo, particularly in Finnoo district and in collaboration with Smart Otaniemi innovation ecosystem. Demand side management will be rolled out throughout the city building stock, including city's rental housing provider Espoon Asunnot.

2.2 Preparing for the monitoring

A plan for the performance monitoring and prospective KPIs has been developed in Work Package 2 for each intervention considering all demonstration actions. As part of the building demonstration actions, the needed data sources and monitoring is being developed simultaneously.

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3 Positive energy blocks in Espoo lighthouse demonstrations

3.1 Introduction to task 3.2

The objective of Task 3.2 is to demonstrate solutions for positive energy blocks and districts. PEDs are expected to generate more energy than they consume annually. JPI Urban Europe defines positive energy districts as "energy-efficient and energy-flexible urban areas or groups of connected buildings which produce net zero greenhouse gas emissions and actively manage an annual local or regional surplus production of renewable energy"[1]. The key driver to developing PEDs is to empower local stakeholders, engage citizens and gain public support for the low carbon energy transition. Ideally, PEDs are independent and locally administered, highly energy efficient entities with local renewable energy generation, storage and distribution, and they interact with the wider energy system. Such interactions include among others energy trade, flexibility services and storage.

PEDs must overcome significant hurdles to persuade citizens, residents, city officials, media and businesses that such districts offer compelling benefits compared to business as usual. It must be proven that PED's can be efficiently integrated with the larger energy system. Investors need to be assured that investing in local solutions provides benefits compared to procuring energy from other means, while connecting surplus energy to the network needs to be technologically and economically feasible for local actors and the surrounding utilities. The economical and technological growth of storage and flexibility solutions is needed to provide incentives for increased distributed production, while ensuring grid stability even at times of peak demand as this production increases. As a rapidly growing city, Espoo is constantly developing greenfield and brownfield sites to host new residents and businesses. As urbanisation is widely accepted to be a driving megatrend globally, city planning functions must prepare to create an enabling environment for citizens, housing companies, real estate developers and businesses to form city districts with sustainable energy solutions, and PEDs will serve as flagships in this process.

Espoo's three demonstration sites are at different stages of development. Within SPARCS a customized approach was developed concerning the implementation of integrated concrete solutions promoting Espoo's transition towards a sustainable urban ecosystem, focusing at first on Positive Energy Districts/Blocks. This comprehensive approach combines electricity, heating, cooling, mobility, fuels, flexibility and storage, controlled by smart solutions to ensure reliability. New models for business and co-creation are investigated to ensure this efficient interoperability between different sectors. The following chapters describe the current status of implementation of the different solutions in the demonstration areas in more detail.

3.2 RES integration in Energy Positive Lippulaiva blocks

The Subtask 3.2.1 RES integration in Energy Positive Lippulaiva blocks focuses on the energy systems in the new Lippulaiva shopping center and the surrounding residential

[1] "Positive Energy Districts (PED)," JPI UrbanEurope, N/A. [Online]. Available: https://jpi-urbaneurope.eu/ped/. [Accessed 04 July 2022].

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building blocks. Leasable gross area of the shopping center alone is 44,000 m^2, with 550 residential apartments and a senior house with approximately 120 apartments. The heated area of Lippulaiva in total is approximately 150 000 m^2. Figure 1 below shows an architecture sketch of Lippulaiva shopping center with residential blocks and the main functions of different buildings in Lippulaiva block. The opening of Lippulaiva shopping center took place on March 31st, 2022.

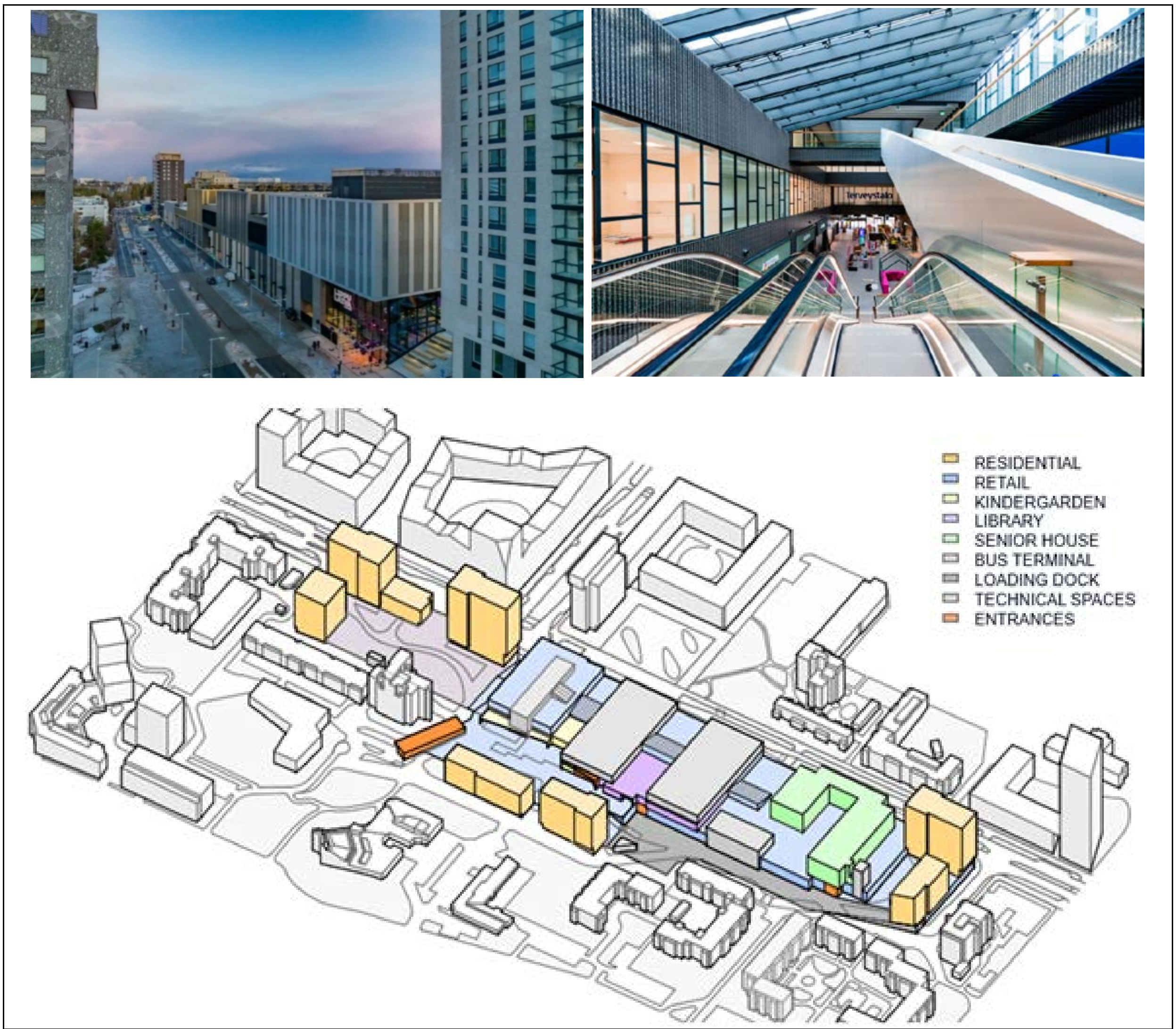

Figure 1. The new Lippulaiva (above) and the main functions of different buildings in Lippulaiva (figures from Citycon Oyj).

The new Lippulaiva shopping centre together with surrounding buildings creates a multi-use district (retail, local services and living) and the potential to achieve zero-energy level and beyond. Heating and cooling demand of Lippulaiva shopping center as well as residential buildings and senior house is mostly covered with heat pump plant. On-site RES production includes a 4 MW regenerative ground source heat pump plant, approximately 50,000 m of bore holes and a PV system with peak power of approximately 634 kWp. Figure 2 below shows measured heating consumption breakdown and hourly heat consumption profile during the first measured period between May and July in Lippulaiva.

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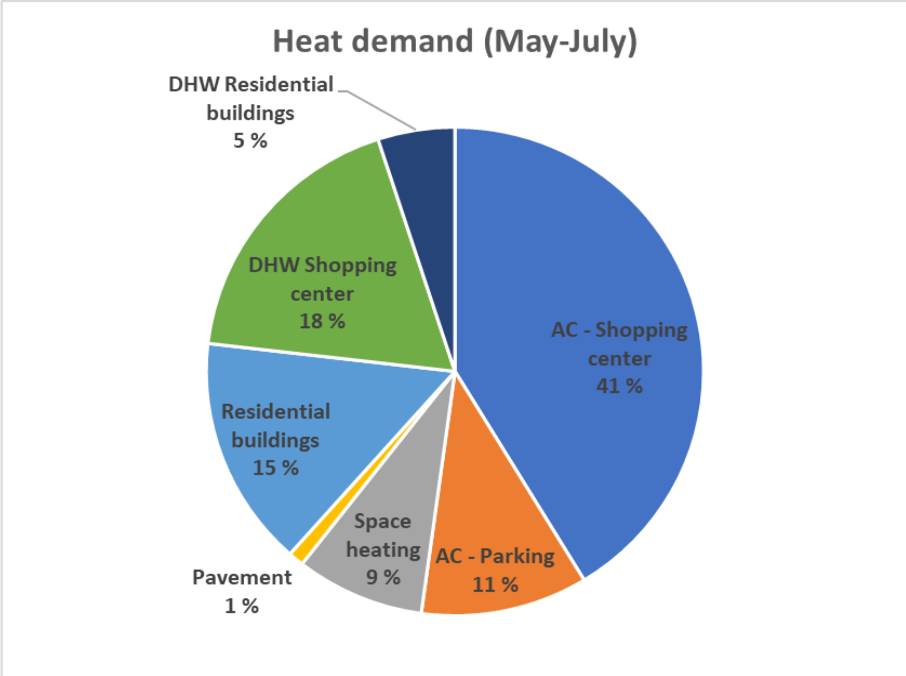

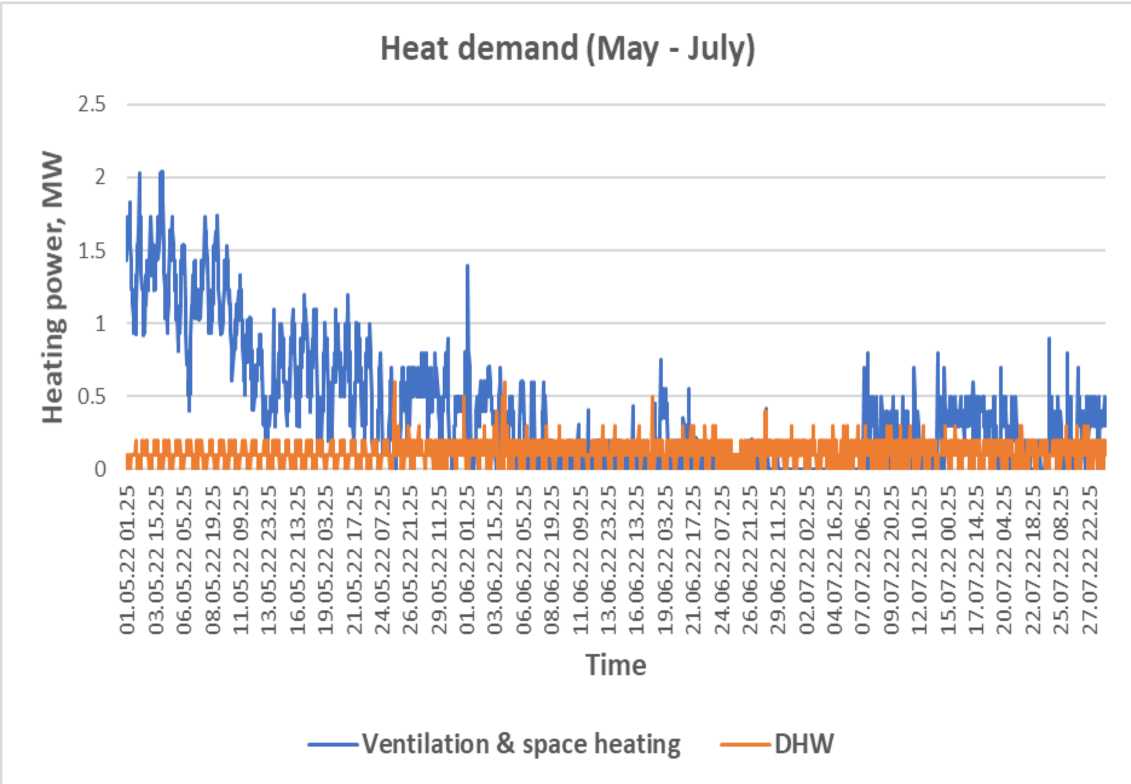

Figure 2. Heating demand breakdown and hourly values in Lippulaiva during the first measured period between May and July 2022. (Source: VTT)

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Figure 3. Adven Energy Station in Lippulaiva (Photo from Adven Oy).

SPARCS interventions (E1) for solutions for Positive Energy Blocks in Lippulaiva are presented in the following tables. Actions E1-1 and E1-2 concentrate on on-site energy production. The target is that heating and cooling demand in Lippulaiva shopping center is mainly covered with on-site geothermal heat with heat pump (system by Adven). Beside the heat pump system, Lippulaiva has district heating connection and electric boiler for back-up heating system and for peak heat demand. The on-site waste heat is utilized when possible. Electricity demand is covered with PV panels (roof and façade) and certified renewable electricity. The capacity of PV panels is assessed in Action E1-2.

The target is that energy consumption and production are smartly controlled. In Action E1-3 the potential to use an electric battery as an emergency power is assessed. Together with this, the smart control system and participation to Nordpool's reserve markets is assessed. With this type of smart electricity control service, it would be possible to decrease electricity costs with smart control strategies, which follow the electricity market price and thus control the consumption level and utilize the electrical battery. The idea is to follow tomorrow's day-ahead market price for electricity and participate in reserve market with battery storage. Simultaneously, the smart electricity control service would cut peak loads and gain savings in electricity costs.

The following tables include a detailed description of the outcomes achieved related to the SPARCS interventions *E1 – RES integration in Energy Positive Lippulaiva blocks.*

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Action E1-1	Optimisation of the NZEB energy system with integrated RES and Virtual Power Plant (ADV CHP-bio, electricity contracted via Nord Pool) based on big data and predictive building control strategies. The system uses a regenerative geo-energy field also storing thermal energy to the ground. The source provides enough heating and cooling for the Lippulaiva blocks. Momentary excess can be exchanged with renewable DH network.
Detailed plan	• To determine the energy consumption profiles in Lippulaiva shopping center and residential blocks (simulations) as well as to describe the consumption of heating, cooling and electricity and possible waste heat sources that can be utilized. • To provide the description of the thermal energy system (heating and cooling) including the Virtual Power Plant, on-site heat recovery and control strategies. • To examine the possibilities of heat recovery from metro tunnel.
Targeted outcome	To achieve Lippulaiva as NZEB with integrated RES and purchased certified renewable electricity with utilizing on-site excess heat, smart control strategies and smart thermal energy storage system.
Roles and responsibilities	CITYCON: As owner of Lippulaiva, Citycon acts as Action leader. CIT provides simulated energy consumption data for partners and ensure that Lippulaiva will be as energy efficient as possible. ADVEN: Adven is the energy partner in Lippulaiva providing heating and cooling energy and investing in thermal energy system. Adven steers and operates energy flows in Lippulaiva block. Adven provides the thermal energy system description including thermal storage. Description of big data and predictive building control strategies concerning heating and cooling is done together with Citycon. VTT: VTT defines the terminologies and calculates the KPI's defined. VTT provides feasibility studies on heat recovery from metro tunnel and connecting geothermal to local DH network together with CIT.
Main achievements till M36	Action E1-1 delivered: • The feasibility study of heat recovery from metro tunnel was made, and the results showed that it is not feasible to utilize heat from metro tunnel. • Energy consumption simulations are done in Lippulaiva shopping center as well as residential block and senior house (heating, cooling and electricity). • Adven has provided system description of geoenergy heat pump system and description of control strategies together with Citycon • Adven's energy system (regenerative ground source heat pump system GSHP) is built and installed. Operation started during construction phase in 2021. • Lippulaiva shopping center has been completed and opened for commercial operation on 31st March 2022.
Outlook (post M36)	Energy monitoring and KPI calculation will be carried out in connection with WP2. Energy flow optimization will be constantly developed and improved as more energy data about user profiles are collected

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Action E1-2	Final dimensioning of the PV plant (capacity depends on the detailed design of the roof structures, and relations between PV and the green roofs)
Detailed plan	To assess the final dimensioning of the PV plant. The target is to maximize the amount of PV panels in Lippulaiva shopping center and the amount depends on the detailed design of the roof structures.
Targeted outcome	The final dimensioning of the PV plant in the rooftop (size, energy production, effect).
Roles and responsibilities	CIT: Providing input data and dimensioning the PV plant. VTT: Calculating needed KPI's (will be done after M36).
Main achievements till M36	Action E1-2 delivered: • Dimensioning of the PV plant has been coordinated to comply with the final architectural implementation of the Lippulaiva block. The final dimensions of PV panels are 1636 panels with a total of 2400 m^2 and 634 kWp. • PV panels are installed on the roof and embedded into the façade. PV panels have produced energy from the beginning of July 2022. • Energy monitoring and KPI calculation will be carried out in connection with WP2.

Action E1-3	Assessing the potential to use a battery energy storage system as emergency power while it provides frequency-controlled reserves and local cost minimization. Control strategies are developed together with business models.
Detailed plan	• To assess the optimal size of battery energy storage • To assess the potential to minimize electricity costs in Lippulaiva by optimizing electricity usage, producing own energy and participating in electricity reserve markets • To assess different control strategies for smart electricity consumption, production and battery usage
Targeted outcome	To assess the potential and describe the benefits of battery energy storage together with smart electricity control strategies and participating in frequency-controlled reserve markets.
Roles and responsibilities	CIT: To assess the potential to use a battery energy storage system and the suitable control strategies as emergency power to minimize costs. VTT: Description of benefits and possible risks for Citycon if participating in reserve markets. To assess different control strategies for smart electricity consumption, production and battery usage. To support Citycon to assess the potential to use a battery energy storage system as emergency power for cost minimizations.
Main achievements till M36	Action E1-3 delivered: • Citycon has decided to invest to an electric battery which is used in reserve markets.

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	• The optimal size of electric battery storage and different control strategies were assessed. As a result, Citycon invested in a 1,5 MW/1,5 MWh electric battery and decided to participate in Fingrid's reserve market (FCR-N). • The battery was purchased and installed. Citycon has been participating in Nordpool's market since July 2022.

Action E1-4	Improving the self-sufficiency of surrounding blocks, emulating the heat export from the ground source heat pump to the surrounding residential building blocks through the local heating network.
Detailed plan	Action E1-4 is closely related to Action E1-1 and the work is partly overlapping. In this action the plan is: • To determine the energy consumption profiles in residential buildings of Lippulaiva • To determine waste heat possibilities from residential buildings and assess their possibilities for heating • To assess the use of Lippulaiva geothermal heat to residential heat • To examine the possibilities of connecting geothermal to district heating network (operated by Fortum)
Targeted outcome	Delivering Geothermal heat and cooling to residential towers and service home to be built in connection to Lippulaiva shopping centre.
Roles and responsibilities	CIT: Providing input data of energy consumption in Lippulaiva shopping center and surrounding residential blocks. Writing the description of consumption. ADV: Providing system description of thermal energy. VTT: Assisting in action when needed. Calculating needed KPI's. Providing feasibility studies on connecting geothermal to district heating network (operated by Fortum) together with Citycon and Adven.
Main achievements till M36	Action E1-4 delivered: • Simulations of energy consumptions in Lippulaiva and energy generation in ground source heat pump (GSHP) were carried out. • GSHP was installed and taken into operation. It primarily provides all energy (heating and cooling) for the shopping center. • GSHP also provides energy for the surrounding residential blocks (8 buildings that will be completed since 2022). Residential buildings utilize energy from GSHP during construction phase. • Feasibility study was conducted regarding possibilities of connecting GSHP with district heating system to realize 2-way energy transfer. • Energy monitoring will be carried out in connection with WP2.

Action E1-5	Proof for the predictability for the energy costs and the profitability of the nZEB solution, paving way for scaling up.
Detailed plan	• To determine base-case where energy costs are compared to • To calculate the energy costs in Lippulaiva • To calculate the profitability of the nZEB solution in Lippulaiva case

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	Due to timing of Lippulaiva construction (opening in March 31st 2022), the costs are calculated based on simulated consumption figures and the proof for the costs will be calculated in project years 4 and 5 with actual consumption data.
Targeted outcome	Finalized energy costs for Geothermal and PV energy production. Cost comparison to base-scenario.
Roles and responsibilities	CIT: Providing consumption and cost data for base-scenario and Lippulaiva case. Providing data for "base-scenario" for cost comparison. ADV: Providing needed input data VTT: Calculating energy costs of Lippulaiva and needed KPI's
Main achievements till M36	Action E1-5 delivered: • Cost analysis can be made after actual energy data is collected, starting from April 2022. • The proof for the costs will be calculated in project years 4 and 5 with actual consumption data M60.

Action E1-6	**Automation steering system development. Development work on optimizing the efficiency of the building automation steering of HVAC systems in connection to geothermal energy production, including system control, air conditioning, demand flexibility and the utilization of weather forecasts. Case Lippulaiva act as pilot.**
Detailed plan	Optimising and developing the automation steering system.
Targeted outcome	By connecting building automation to Adven energy production automation we are able to optimize more efficiently energy production and minimize expenses and CO2 emissions.
Roles and responsibilities	ADV: Specifying interface and steering procedure together with building automation service provider CIT: Connecting Adven to Citycon's chosen building automation service provider
Main achievements till M36	Action E1-6 delivered: • Contract with service provider (Schneider Electric) was signed • Automation system was installed and taken into operation using Granlund Manager as a tool • Automation system operates in the Lippulaiva and takes care of energy efficiency; monitoring will be done as part of WP2 • Efficiency potential has been identified especially in the area of the indoor ventilation steering (HVAC). • Next, more detailed information of the building technology system (HVAC) will be analyzed in order to start planning interfaces and steering features.

Actions related to Lippulaiva energy systems have progressed according to the plan. The feasibility study of heat recovery from metro tunnel was made, and the results showed that it is not feasible to utilize heat from metro tunnel mainly due to timetable of the metro construction not allowing any modifications of technical solutions.

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However, Lippulaiva utilizes onsite energy as much as possible and it has been carbon neutral in terms of energy use from the opening day in March 2022.

GSHP system supplied by Adven began operation already in early 2021 to provide heating to the construction site. The operation of the heating and cooling system, the utilization of waste heat, energy storage and the control strategy are described in more detail with connection to the thermal energy system description.

The final dimensioning of PV system was also conducted resulting in a slightly smaller PV system than originally planned. The reason for this is the changed architecture of Lippulaiva. In the end, the size of the PV plant in Lippulaiva shopping center's roofs is 526 kWp. Additional PVs for façade were dimensioned and the peak power for façade PV system is 51 kWp (Figure 4). There will also be PV system (57 kWp) on roofs of residential buildings. The rest of the electricity demand is covered with certified renewable electricity from the grid.

Figure 4. PV panels embedded in the facade and on the roof in Lippulaiva shopping center. (Source: Citycon).

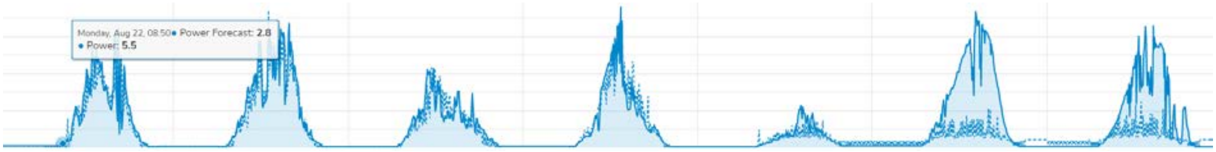

Figure 5. Example of power of PV panels for one week in August 2022. (Source: Citycon).

Work done in Action E1-3 (Assessing the potential to use a battery energy storage system) led to a large investment of electricity battery and smart control strategies to Lippulaiva. Citycon invested in a 1,5 MW / 1,5 MWh electric battery with which Lippulaiva participates in Fingrid's reserve markets balancing the national grid and gaining extra income.

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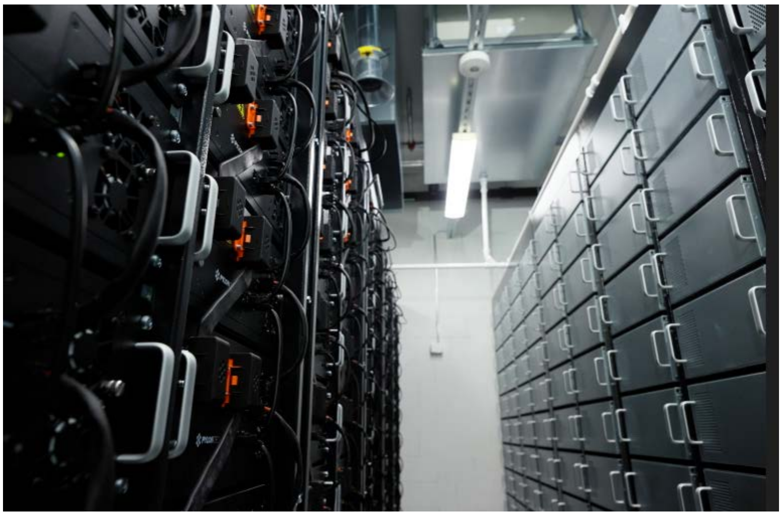

Figure 6. The electricity battery in Lippulaiva. (Source: Schneider Electric).

Optimization of energy use is done with smart control strategies. As Lippulaiva's thermal system runs with electricity (GSHP heat pumps and electric boiler) and shopping center has different electric consumption, Lippulaiva has a great potential to optimize its energy use. The aim is to connect the electricity system and the heating system so that the control strategies of the systems optimize energy consumption and save the customer energy costs. The principle figure of Lippulaiva energy system is showed in Figure 7.

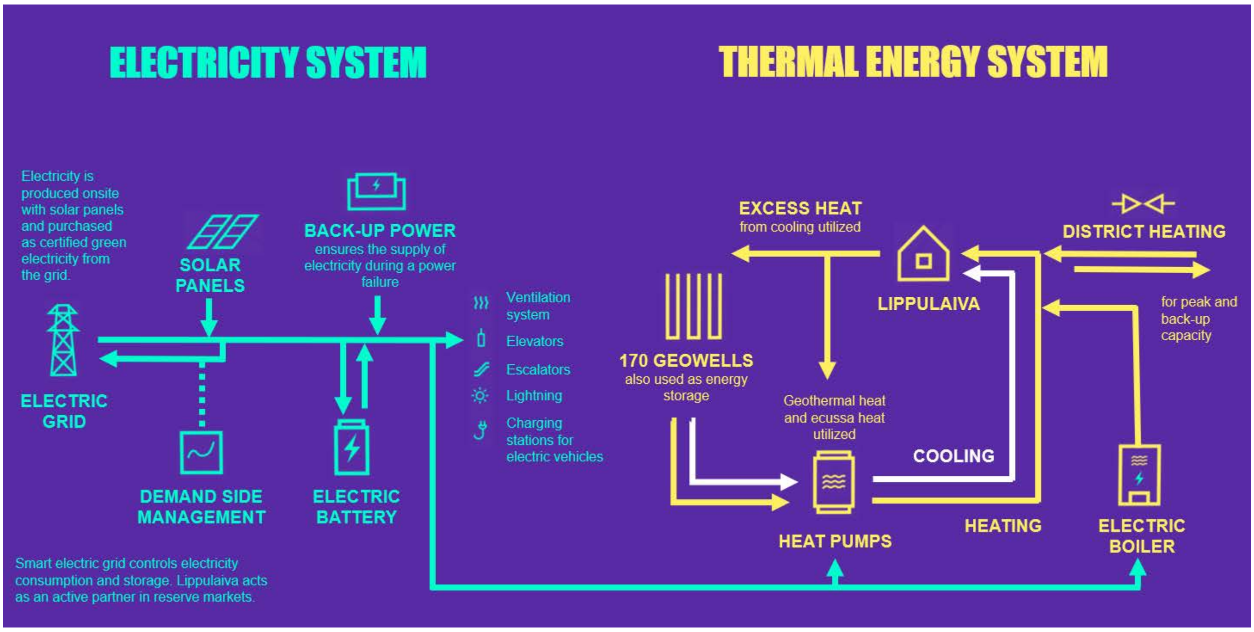

Figure 7. Principle figure of Lippulaiva's energy system and connections of electricity system to thermal system. (Source: Citycon).

General technical description of the system in Lippulaiva

Summary of general data regarding the whole system of Lippulaiva is depicted in Figure 8.

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The energy system consists of 4 000 kW of heat pumps (8 compressors total) with an environmentally friendly R1234ZE refrigerant, 4 000 kW of a district heat extension and 500 kW of electrical boiler. The district heat and the electrical boiler are used if eventually for the peak load in cold winter days as well as backup during the maintenance and service work. The energy system provides heating and cooling energy for the Citycon Shopping Centre and for the other residential and service buildings located in the same block (Lippulaiva City Center). The heat pumps are using 171 energy wells with average of 314 m depth which have been drilled under the new buildings on both sides of the subway. Also, the exhaust heat from the cooling machines of the 4 convenient stores are integrated as a source of heat.

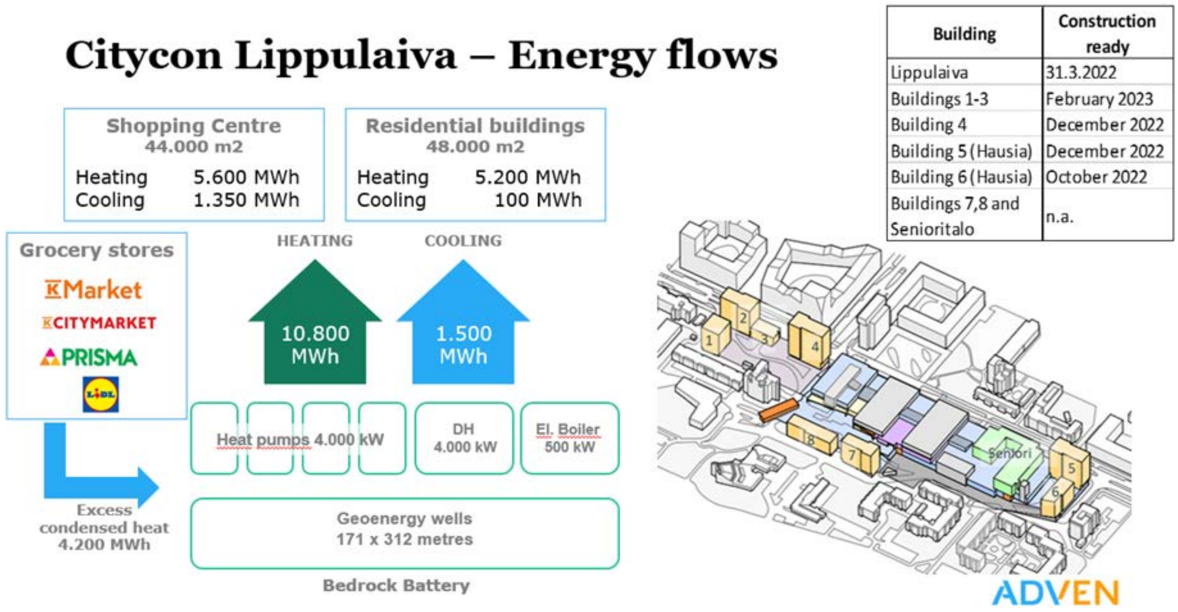

Figure 8. Layout and basic data regarding the technical systems in Lippulaiva. (Source: Adven)

Briefly the systems operation is as follows:

- Heating of the Lippulaiva block
  - o Operating mode in general. The heating process will become active when the outdoor temperature sinks below +15C for more than 2 hours. The circulation pumps on the evaporator and the condenser side of a one of the heat pumps will start with 20% power. The heat pump will start the first compressor on 25 Hz which is the minimum capacity of the compressor. The compressor will run with the frequent controller the frequent and there for the power of the compressor up to 60 Hz which is the maximum frequent of the compressor. At the same time the circulation pumps of the heat pump will increase the power by keeping the temperature difference of evaporation side in 5 K and the condenser side in 15 K.
- Domestic hot water production for Shopping Centre
  - o The domestic hot water tank has the temperature sensors which measure the top and the bottom temperature of the tank. If the temperature on the bottom of the tank drops down to 50C will the 3-way valve turns to heat the domestic hot water tank. The heat pump will get the setup value of 65C and the circulation pumps on evaporator and condenser side will turn on for 20%

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power. One minute after the circulation pumps are on, the first compressor starts with 25 Hz power.

- Harnessing excess heat from the freezing machines of the grocery stores
  - The four convenient stores located in the Shopping Centre are producing exhaust heat when cooling down the groceries. The excess heat is recovered by the circulation pumps in Adven Energy Center. The double circulation pumps P7 in each of the four (4) heat recovery network are working one at the time every second month. The circulation pumps are increasing the speed according to the temperature difference Te16 and the return temperature in the system.
- Cooling of the Shopping Centre in summer
  - In addition to the space cooling, the Shopping Centre requires air-condition cooling when the outdoor temperature raises over +10C. When the outdoor temp TE2 increases over +10C for more than 1h then the circulation pump P5.2 runs with the minimum power of 20% and the 3-way valve V11 will adjust by keeping the ongoing temperature TE26 at +10C. If the valve V11 is 100% open and the temperature rise above 10C, then the circulation pump will increase the power until the required +10C temperature is reached.
- Cooling of the Shopping Centre in winter
  - Space cooling is required all around the year. The cooling will be delivered from the energy wells over a heat exchanger located in Adven Energy Center. The circulation pump P5.2 runs with the minimum power of 20% and the 3-way valve V12 will adjust by keeping the ongoing temperature TE28 at +10C.
- Domestic hot water production for the Residential and Service buildings
  - The domestic hot water is produced by the separate 700 kW heat pump. The circulation pump P8 circulates the heating water between the domestic hot water tanks in the apartment buildings and the Adven Energy Center. If the return water is under +55C, the valve V13 will open and the circulation pumps P4 and P6 of the 700-kW heat pump will start with the minimum frequency. The heat pump will start after one minute and will get the set point of 65C.
- Cooling of the residential buildings
  - The apartments 4, 5, 6 and senior building have their own cooling pipes from the geoenergy field and they have the possibility to use the cooling heat exchangers to receive cooling energy. Each of the heat exchanger are equipped with a circulation pump that will adjust the speed according to the ongoing temperature of the cooling network by keeping it in +10C.

Profitability study of the two-way district heating

The surplus capacity is calculated from the design capacity of the heat pumps (3600 kW) and the heat demand of Lippulaiva block which includes the shopping centre and the neighbouring apartment buildings.

The selling possibilities of the surplus heat to the local district heating network is from the return to the supply pipe or from the return to the return pipe. The supply temperature of the local district heating network at Espoo is quite high i.e. the maximum is +115 °C, at winter design outdoor air temperature -26 °C and minimum 70 °C, at

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summer times. The minimum delivery temperature for the supply is expected to be 5 °C higher than the supply temperature.

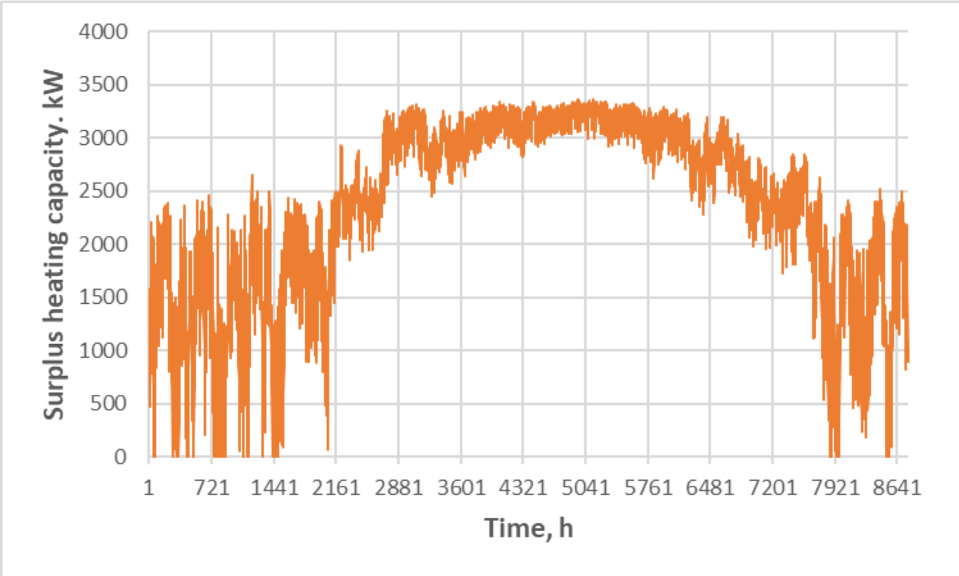

Figure 9. Surplus heating capacity available for heat trading. (Source: VTT)

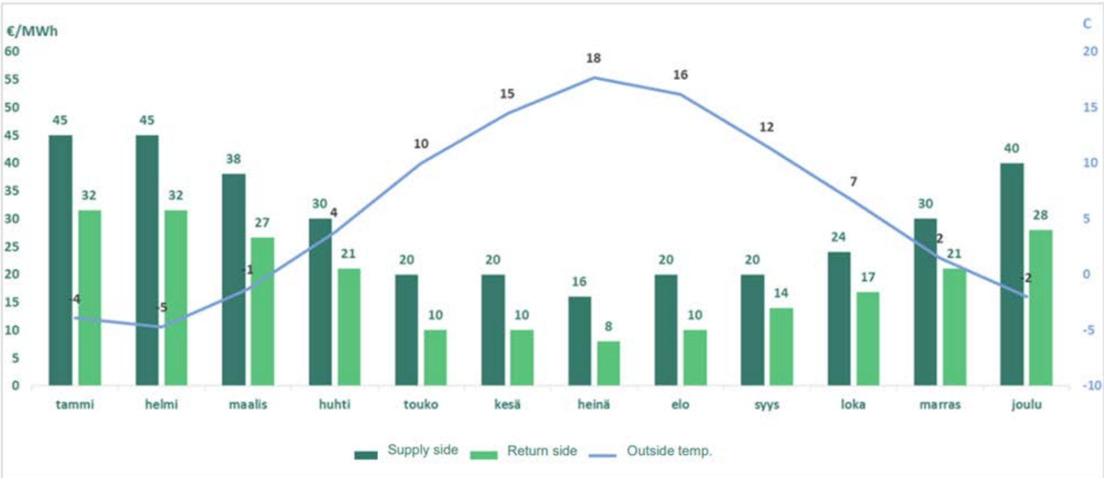

Figure 10. Indicative excess heat purchase price (in €/MWh) according to the average monthly temperature, VAT 0%. (Source: Fortum)

The purchase prices for open district heating in Espoo for the supply and return sides of the district heating network are given in Figure 10. The electricity price to run the heat pumps is given as constant 85 €/MWh.

Analysis covered the following cases:

- Case 1: selling heat to the return side of the district heat with existing heat pumps (return-return connection)
- Case 2: selling heat to the return side of the district heat with booster heat pump (return-return connection)
- Case 3: selling heat to the supply side of the district heat with booster heat pump (return-supply connection)

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In addition to the three cases presented earlier above, a reference case without selling was included. All the cases were analysed on hourly base for a whole year.

To understand the differences in the profitability of the cases, we will look at the key parameters affecting the energy costs to run the heat pumps, namely condensing and evaporating temperatures.

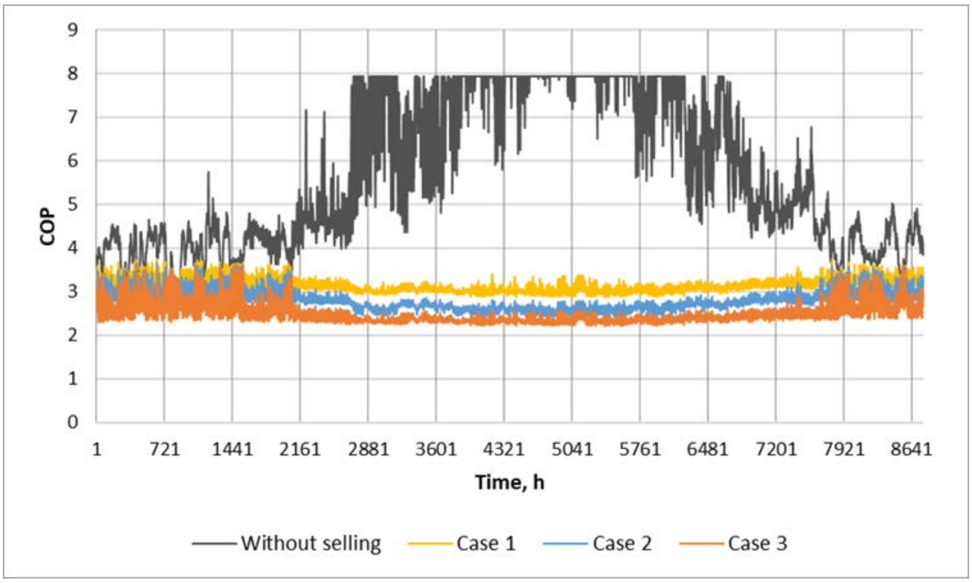

Figure 11. Hourly COP values for all cases and reference case without selling. (Source: VTT)

The calculated energy efficiencies of the systems (COP) are presented in Figure 11. The most energy efficient system, i.e. highest COP, is with reference system when no heat is sold. The difference is most clear in the summer time when space heating demand is lowest and the condensing temperature is low and evaporating temperature is high compared to the other cases.

This study indicates that in spite of many simplifications and uncertainties in the analysis, the profitability of selling the heat to the district heating network is not feasible with available selling tariffs.

Analysis has shown that the Lippulaiva's energy system occasionally contains thermal energy that from the technical viewpoint could be transferred to the district heating company's network. However, the temperature level of the energy to be transferred is not sufficiently high to meet the specifications of the district heating company. The temperature can be raised with compressors, but the price paid by the district heating company does not cover production costs.

3.3 Smart energy solutions for self-sufficiency in the Leppävaara center

Subtask 3.2.2 Smart energy solutions for self-sufficiency in the Leppävaara center focuses on increasing efficiency, flexibility and self-sufficiency through digital tools and through local thermal energy production.

Leppävaara is one of the fastest growing areas in Espoo and Sello Center is the local Energy hub of Leppävaara (Figure 12). Sello multipurpose centre has an area of

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102 000 m^2 including shops, a library, concert hall, and movie theatre. Sello center has 2900 parking lots that includes 24x22kW and additional EV charging stations are planned. Sello receives approximately 23 million visitors yearly.

Figure 12. PV Panels on Sello Center. (Source: Siemens)

In Action E5-1 Sello's thermal energy processes are modelled to understand the potential increased energy efficiency, self-sufficiency, and thermal flexibility. In Action E5-2 Sello's flexibility potential is realized by providing the thermal flexibility to local district heating company (Fortum). In Action E5-3, increasing the self-sufficiency through deep heat geothermal well is evaluated using the Power System Simulator PSS.

Details of SPARCS interventions E5 Solutions for Positive Energy Blocks in Sello are presented in the following tables.

Action E5-1	Predictive model for the storing energy to the building structures and battery storage to be created and evaluated.
Detailed plan	• Define solution architecture • Integrate data flow from Sello BMS to VTT platform • Install thermal submeters for needed granularity • Calculate time constant and create prediction algorithms for storing energy (heat and cool) in Sello based on physical structure (if available), historical and real time energy data: energy, indoor environment, weather and (visitors and people flow, if available). • Integrate the time constant and prediction algorithm to Sello energy management system via APIs • Integrate Sello energy management system through APIs to local DH company for DH demand side management Additional, if resources are available: • Creating a BIM model of Sello block (in IfcSpace format) • Integrate the prediction model to Digital Twin model via APIs
Targeted outcome	Predicts 48hrs ahead Sello's heating and cooling flexibility with high accuracy based on the different heating and cooling strategies. Use the prediction model to provide increased flexibility for DH DSM in E5-2 and demand peak optimization. Continue co-operation beyond SPARCS

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Roles and responsibilities	SIE: Define solution architecture, provide data needed and create APIs towards VTT and Fortum, integrate algorithm to BMS control system, acquire BIM model creation VTT: Define solutions architecture, calculate time constant and prediction algorithm, (integration to digital twin, temperature data linked to 3D BIM-model to e.g. visualize temperature, CO_2 and RH, changes during demand response period)
Main achievements till M36	Action E5-1 delivered: • Solution architecture defined and API created • Time constant defined based on historical consumptions • Prediction algorithm is developed. Prediction is automatically updated each day via machine learning neural network models online for the next day. • Sello energy management system connection to local DH company (Fortum) established through APIs. DH demand side management using Sello's flexibility (as part of Action E5-2) is operating • BIM model and Digital Twin of Sello have been created Monitoring of the results will be carried out in WP2 Integration of the prediction model to Digital Twin model via APIs

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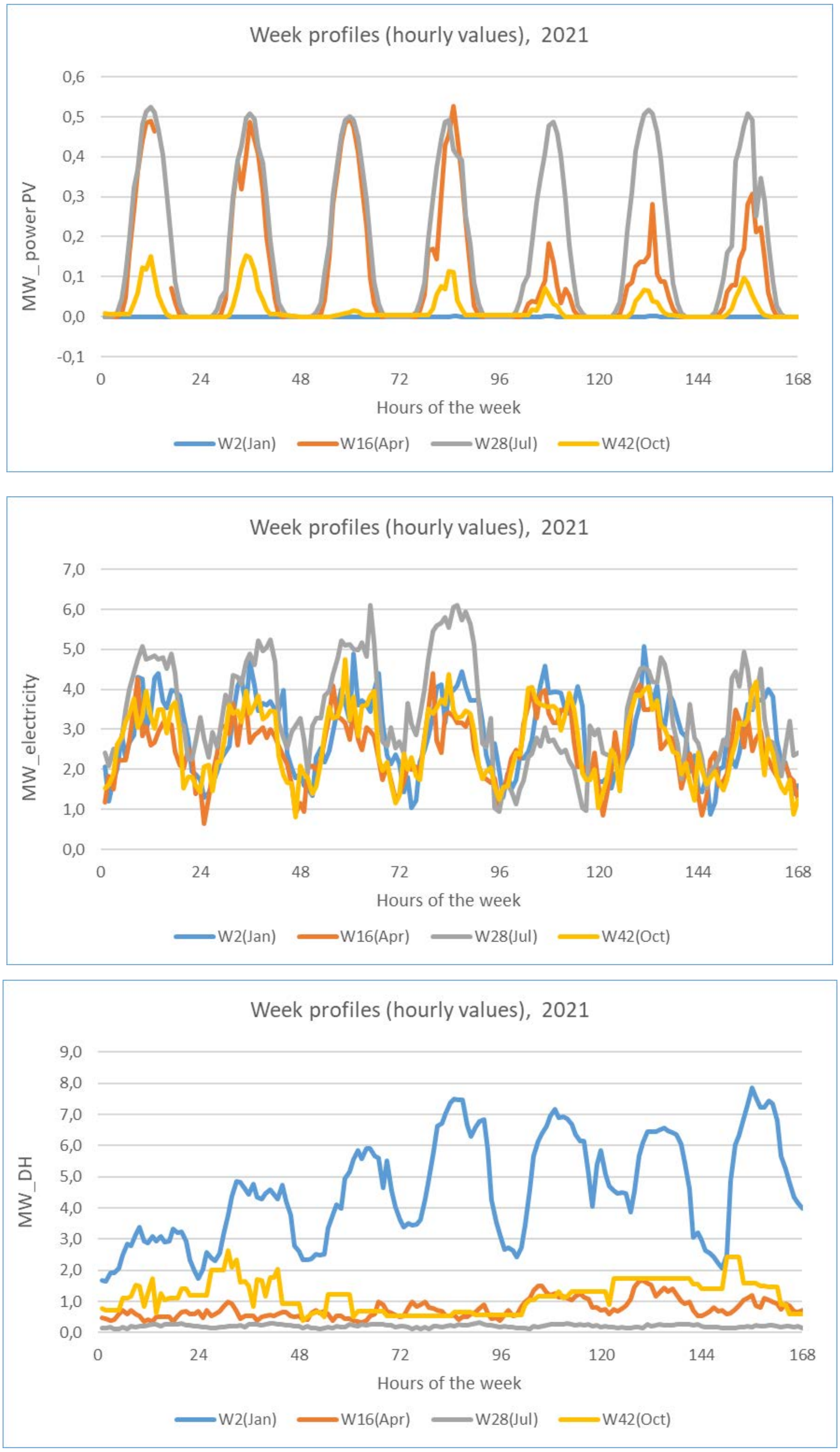

Figure 13. Hourly performance of PV, Electricity and District Heating in Sello during four weeks in different seasons of 2021. (Source: VTT)

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Action E5-2	Integration with the local district heating grid operated by Fortum (Bio oil Plant 40 MW) for selling cooling/heat and heat demand side management.
Detailed plan	• Define system architecture • Provide flexibility data via API to Fortum • Execute flexibility based on Fortum's signal via API
Targeted outcome	To lower CO_2 emissions level of local DH. To enable consumers to become active part of the energy sector by providing flexibility.
Roles and responsibilities	SIE: Define system architecture, coordinate the work with Fortum and Sello, responsible for implementation
Main achievements till M36	Action E5-2 delivered: • Technical solution developed and engineering completed • Provision of flexibility data via API to Fortum • Execution of flexibility based on Fortum's signal via API
Outlook (post M36)	Full scale operation of Sello's DSM flexibility with district heating Monitoring of the results will be done as part of WP2

The targeted outcomes of the action were:

- To lower CO2 emissions level of local district heating.
- To enable consumers to become active part of the energy sector by providing flexibility.

The plan to achieve the set targets included following steps:

- Define system architecture
- Provide flexibility data via API to Fortum
- Execute flexibility based on Fortum's signal via API

The goal of the action was to create messaging interface between the Siemens building management system (BMS) and Fortum heat plant automation, send the required flexibility calls via the new interface and adjust the heating demand based on the calls. The solution is implemented as a pilot project in the Shopping centre Sello in Espoo, Finland.

The created solution includes flexibility forecast and the actual demand response request sent by Fortum. The required actions are made by Siemens BMS, which adjusts the required flexibility based on the consumption at the time. The messages are used as adjust messages varying between -100…0%, where -100% means full response and 0% means that no action is needed.

The system was tested first time in the winter 2020–2021. The experiences and data collected during the heating season were analyzed during the summer. Some minor program adjustments were implemented to the BMS before the next winter to improve the operations. The adjustments showed clear improvements during the next winter. In 2021 the total peak heating power demand was 11.4 MW and in 2022 the peak was 7.7 MW. This is a drop of 32% in peak power need.

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The heating of Sello is separated in two systems: the shopping center has one system and the entertainment center second one. Below in the graph are presented the heat demands in different temperatures (°C) of January to March both in 2021 and 2022. First is the heat demand of the shopping center and second the entertainment center.

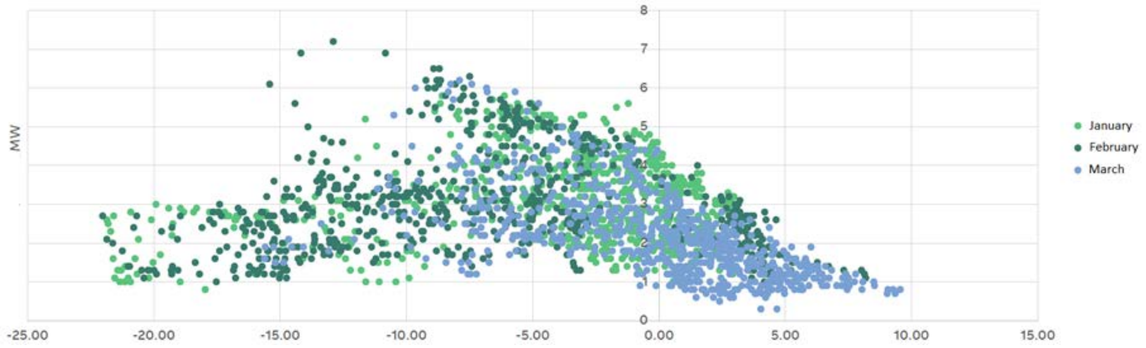

Figure 14. Heating demand of the shopping center in January – March 2021. Source:Siemens

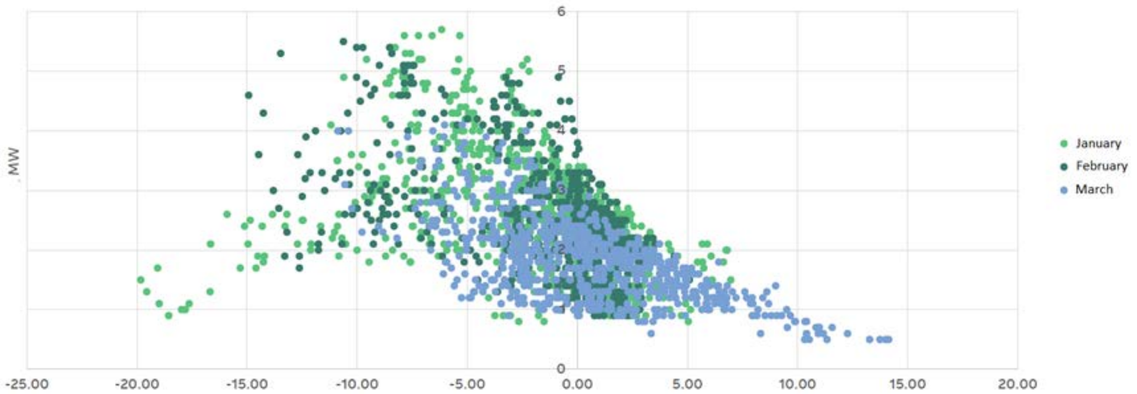

Figure 15. Heating demand of the shopping center in January – March 2022. Source:Siemens

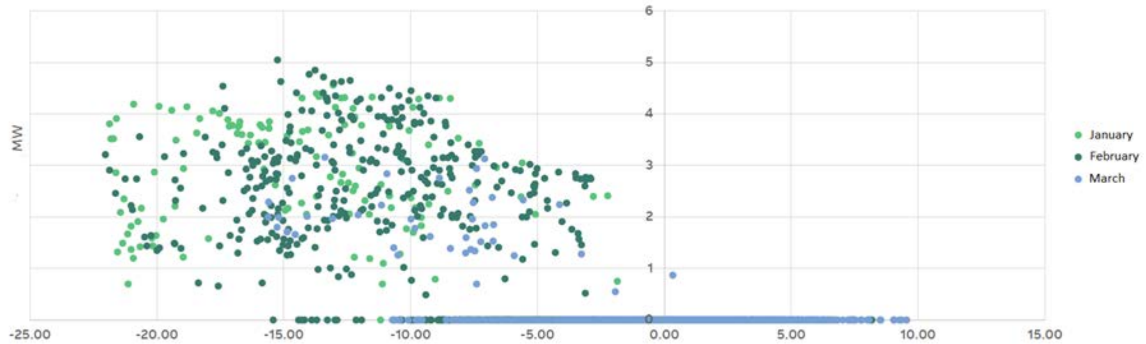

Figure 16. Heating demand of the entertainment center in January – March 2021. Source:Siemens

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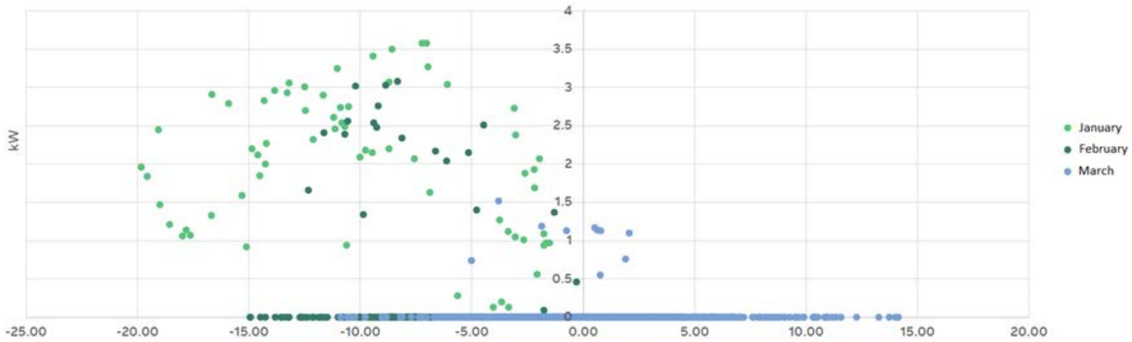

Figure 17. Heating demand of the entertainment center in January – March 2022. Source:Siemens

As can be seen from the graphs, the heating power demand has decreased significantly, and the highest peaks have disappeared. Therefore, the consumption is significantly more spread over time instead of sudden spikes in demand, which is one of the goals of the demand side management.

Below is presented data series of Fortum how the district heating demand and production vary. Normally the heat production is adjusted based on the consumption (orange line). In other words the green area would match the orange line. Instead, now part of the consumption is adjusted, so that the production could be steadier at the more optimal, high efficiency level. The solution could also allow avoiding the use of peak heat demand plants, which are typically oil or gas based plants.

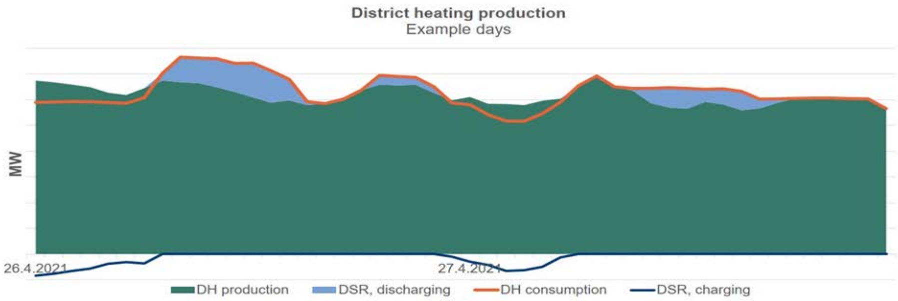

Figure 18. Fortum district heating production and consumption, example of two days. Source: Fortum

This can also be seen below in the Table 3, which represents the 15 highest heating demand hours of January-March in 2021 and 2022.

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Table 3. highest district heating demand hours in the entertainment center in 2021 and 2022. Source: Fortum

	2021			2022		
#	Timestamp	Power, MW	Outdoor temperature, °C	Timestamp	Power, MW	Outdoor temperature °C
1	12.2.2021 11:00	5.05	-15.25	11/01/2022 16:00	3.58	-7.03
2	12.2.2021 12:00	4.85	-13.77	11/01/2022 17:00	3.58	-7.23
3	5.2.2021 12:00	4.77	-14.00	11/01/2022 15:00	3.5	-8.58
4	5.2.2021 13:00	4.72	-13.43	11/01/2022 14:00	3.41	-9.43
5	12.2.2021 13:00	4.65	-12.38	11/01/2022 18:00	3.27	-6.97
6	5.2.2021 15:00	4.63	-12.73	11/01/2022 13:00	3.25	-11.03
7	6.2.2021 9:00	4.63	-15.12	03/02/2022 13:00	3.08	-8.33
8	5.2.2021 14:00	4.60	-13.03	08/01/2022 12:00	3.07	-8.72
9	17.1.2021 11:00	4.56	-13.05	10/01/2022 18:00	3.06	-13.20
10	18.2.2021 10:00	4.54	-17.40	11/01/2022 19:00	3.04	-6.10
11	6.2.2021 12:00	4.50	-10.83	03/02/2022 14:00	3.03	-8.87
12	6.2.2021 13:00	4.45	-9.98	03/02/2022 15:00	3.02	-10.22
13	4.2.2021 10:00	4.41	-14.50	10/01/2022 17:00	3.01	-12.50
14	5.2.2021 17:00	4.41	-13.45	10/01/2022 19:00	2.96	-13.85
15	17.1.2021 10:00	4.40	-13.72	11/01/2022 11:00	2.93	-13.28

The peaks in 2022 are around 30% lower than in 2021. Also, the highest demand take place typically between 13.00 and 19.00 in 2022 whereas the peaks were earlier between 11.00 and 14.00 in 2021. The high demand has therefore shifted 2–4 hours later.

This kind of behavior is very desirable since high power peaks may cause firing up of backup heat plants which are usually based on gas and oil. Instead, the more consistent consumption allows the actual heat plant to operate with better efficiency and use more renewable heat sources. The more buildings and the more heating systems are connected to the demand side management, the higher potential for flattening the demand curve exist and the required response of an individual system can be smaller. Consequently, the CO_2 emissions and dependency on fossil fuels will be significantly lower than without demand side management.

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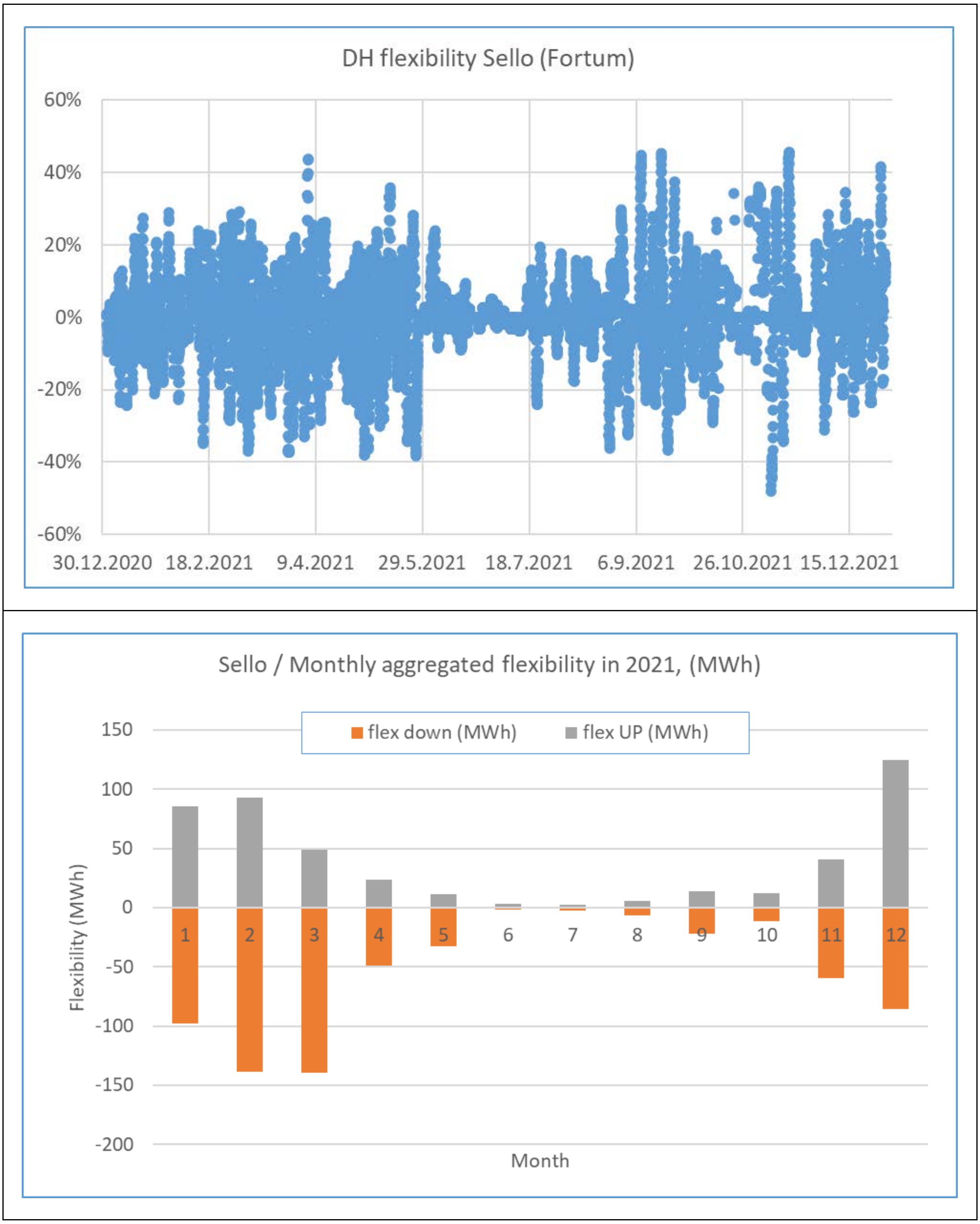

Figure 19. Direct hourly and aggregated monthly values of provided District Heating flexibility of Sello in 2021. (Source: VTT)

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Action E5-3	Evaluate increase of self-sufficiency through the Sello extension. Evaluate deep heat station in new build.
Detailed plan	• Define scope of the study and limitations. • Gather input data from Sello and solution providers. • Analysis and conclusions.
Targeted outcome	Increase of self-sufficiency of a Sello Block. Understanding technical barriers and commercial potential compared to DH. Understanding technical barriers and commercial potential of P2P heat trade.
Roles and responsibilities	SIE responsible for defining the scope, gathering the input data and analysis.
Main achievements till M36	Action E5-3 delivered: • Scope of the study is defined and limitations explored • Input data from Sello and solution providers are collected • Completing Sello deep heat geo-well simulation, first simulation

Some observations from the feasibility study regarding Action 5-3.

The heat effect delivered by a vertical energy-well is determined by the surrounding ground temperature, heat conductivity of ground, thermal gradient in the vicinity of the borehole, and the temperature of the circulating fluid.

Two basic approaches for the borehole heat exchanger could be used for a deep-well case, these are U-tube collector or coaxial pipes, and those are shown in Figure 20. Often existing borehole heat exchangers employ U-tubes, but simply adjusting this to the deep-well case would not come without problems. For example, with increasing depth the heat carrier flow rate needs to be increased to effectively extract the heat from the borehole and to avoid thermal shunting of the forward and return flows. At the same time, pressure losses in the U-tube would increase, which would require increasing the diameter of the pipe. Compared to the U-tube, the borehole with a coaxial pipe uses a larger portion of the cross-sectional area of the borehole as the flow area, and that is why it fits better higher mass flow rates. Another benefit of a coaxial borehole is that it could reduce the internal thermal resistance in the borehole heat exchanger and increase the temperature of the heat carrier fluid, which improves the performance of the heat pump system.

Summarizing, a coaxial borehole heat exchanger seems more suitable for deep heat extraction. As an example of the potential of the deep coaxial borehole heat exchanger is that a single 800 m borehole could provide more heat than 6 conventional 300 m U-pipes.

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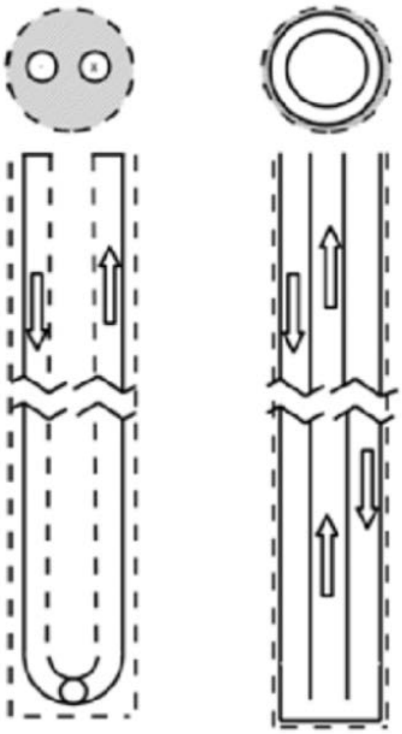

Figure 20. Schemes of borehole heat exchangers. On the left: single U-tube collector and on the right: coaxial pipe. (Source: ResearchGate)

Simulation introduction:

The simulation has been analyzed by using PSS®DE (Power System Simulator for Distributed Energy). This tool is specifically designed by Siemens to realistically model different energy systems. The tool allows to analyze complex combinations of various systems so that the technical and economic feasibility throughout the design, commissioning, and operation phase of such systems can be assessed. The simulation includes project specific loads and prices.

Heating loads for the simulation has been taken from year 2021 using Siemens navigator, which collects data straight from energy meters in Sello. Cooling load has been calculated using the electricity consumption that is used for cooling systems. This data was also collected from 2021. The Sankey diagram in Figure 21 shows the different heating and cooling loads in Sello. Figure 22 shows the same diagram with only district heating.

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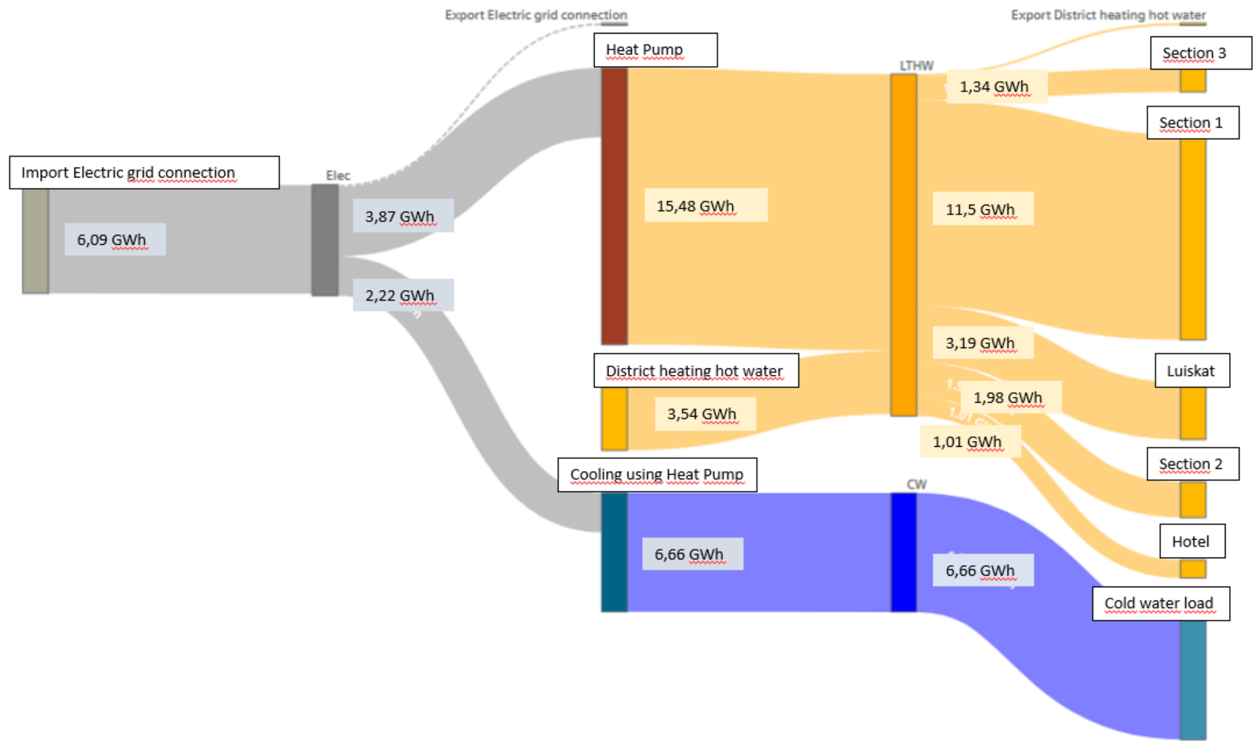

Figure 21. Sankey diagram showing Sello's heat demand per area when using a deep heat station. (Source: Siemens)

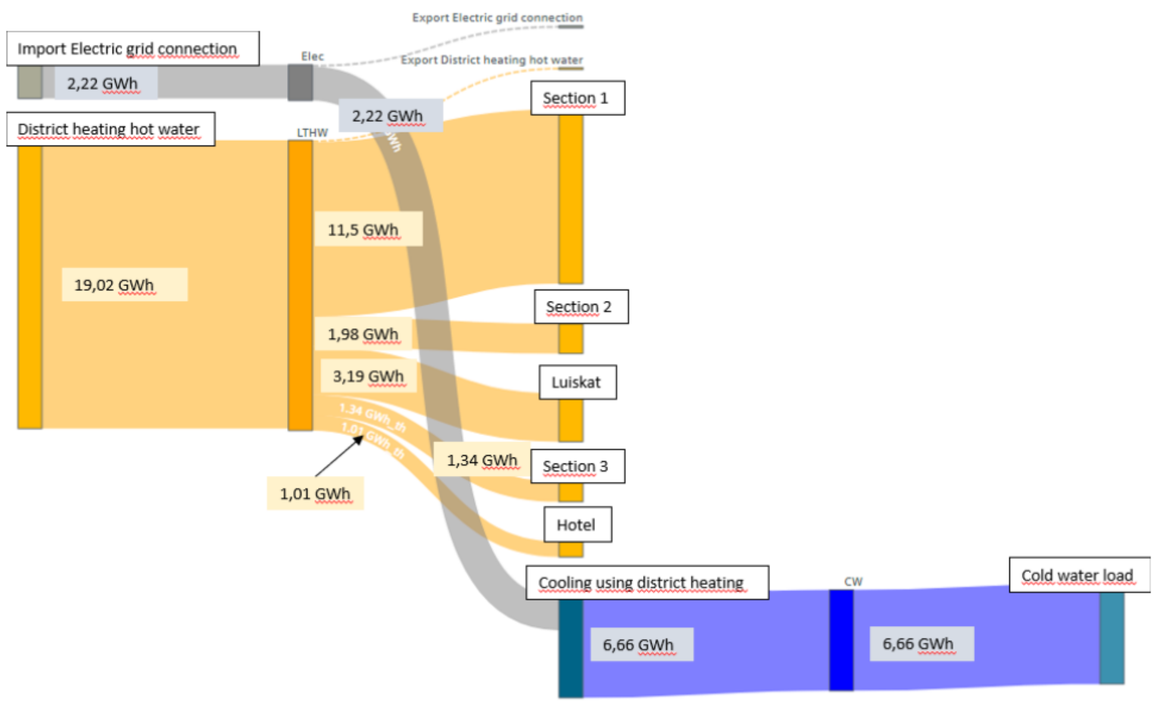

Figure 22. Sankey diagram showing Sello's heat demand per area when using only district heating. (Source: Siemens)

The energy prices were imported for every hour for a year. The electricity price for the simulation was taken from Nord Pool 2021 history data. District heating price is created

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using the most recent information from Fortum. For district heating, we also used an annual multiplier of 15% for the district heating price. This multiplier was also taken from Fortum webpages. Figures below show all the annual energy flows and energy prices.

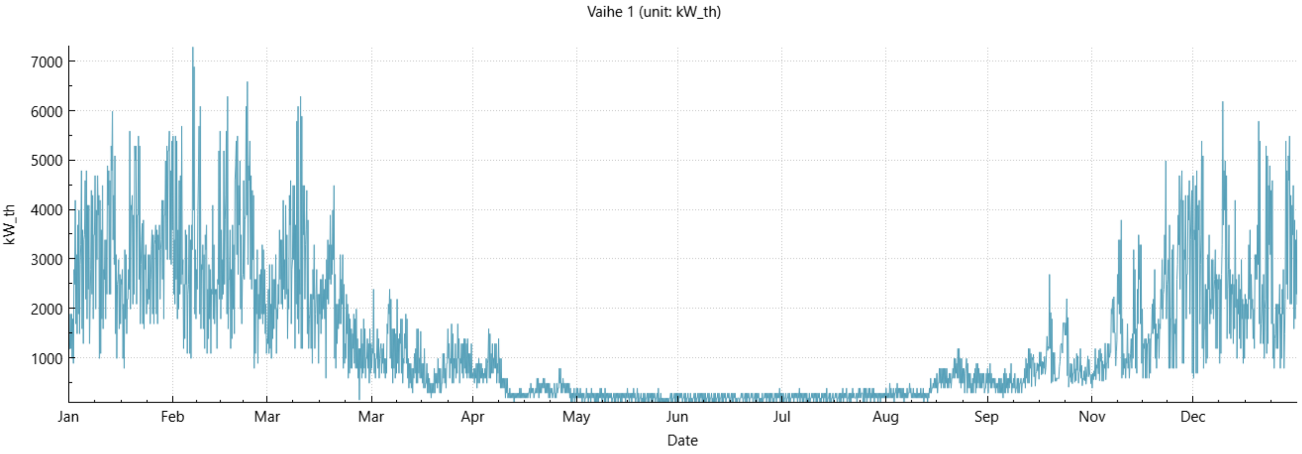

Figure 23. Vaihe 1 (Section 1) annual heat demand. (Source: Siemens)

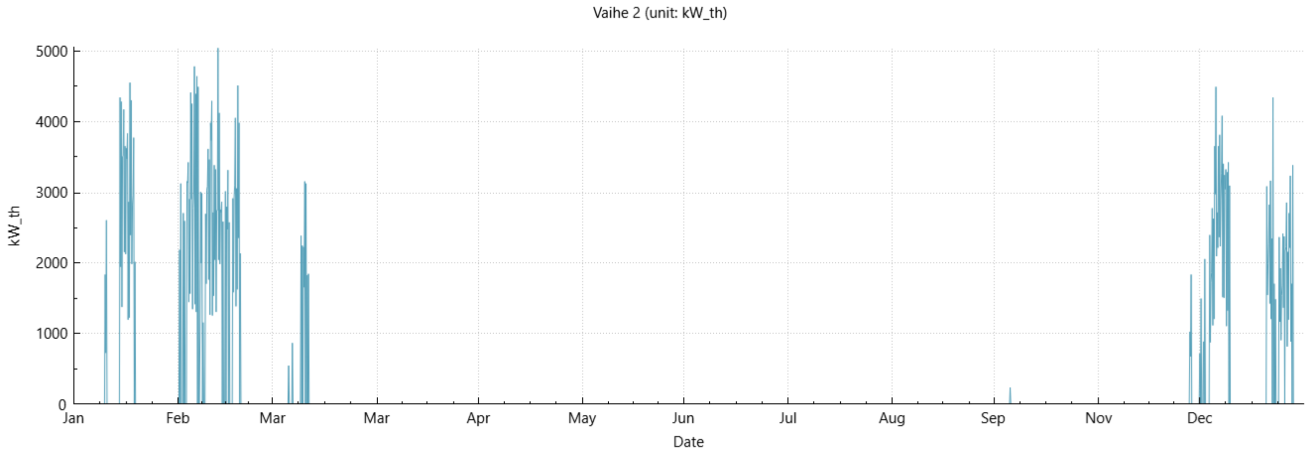

Figure 24. Vaihe 2 (Section 2) annual heat demand. (Source: Siemens)

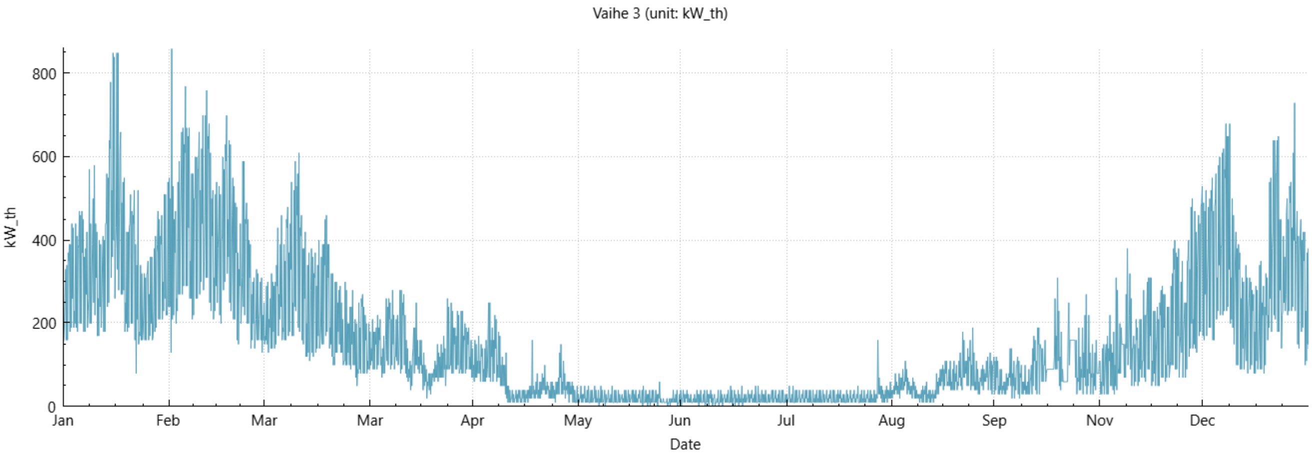

Figure 25. Vaihe 3 (Section 3) annual heat demand. (Source: Siemens)

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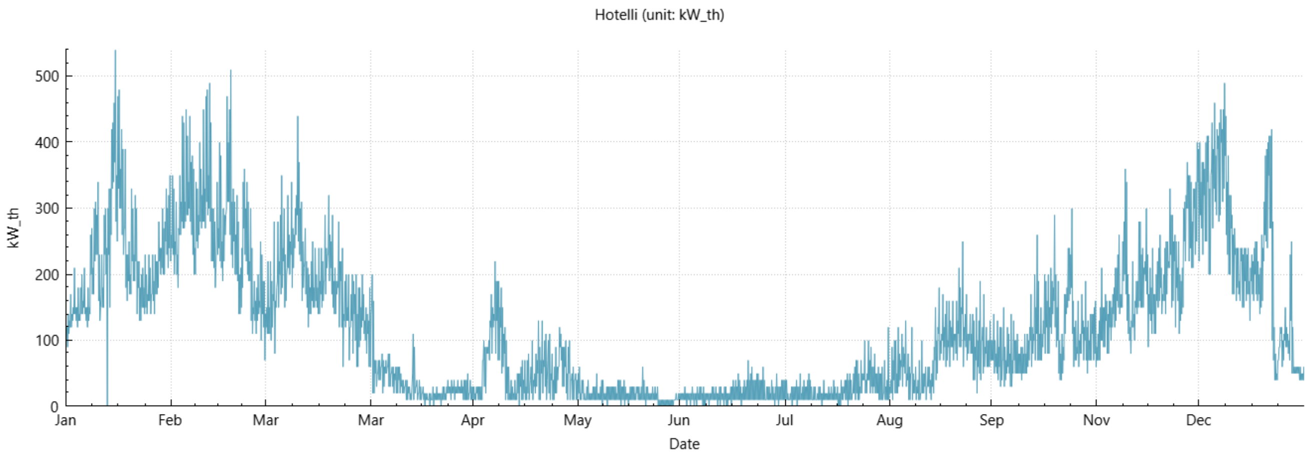

Figure 26. Hotel annual heat demand. (Source: Siemens)

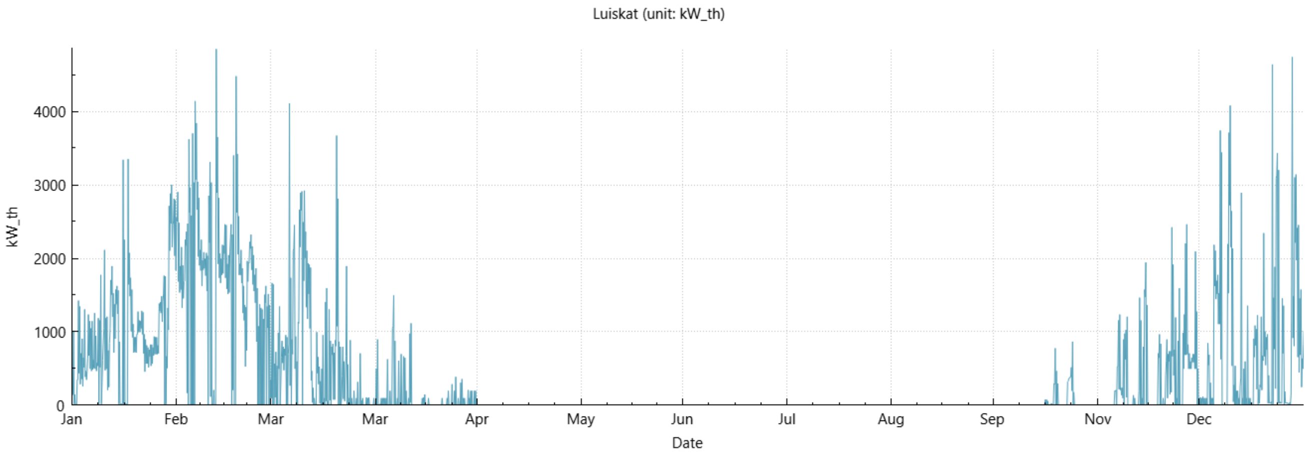

Figure 27. Pavement slope heating (snow melting) annual heat demand. (Source: Siemens)

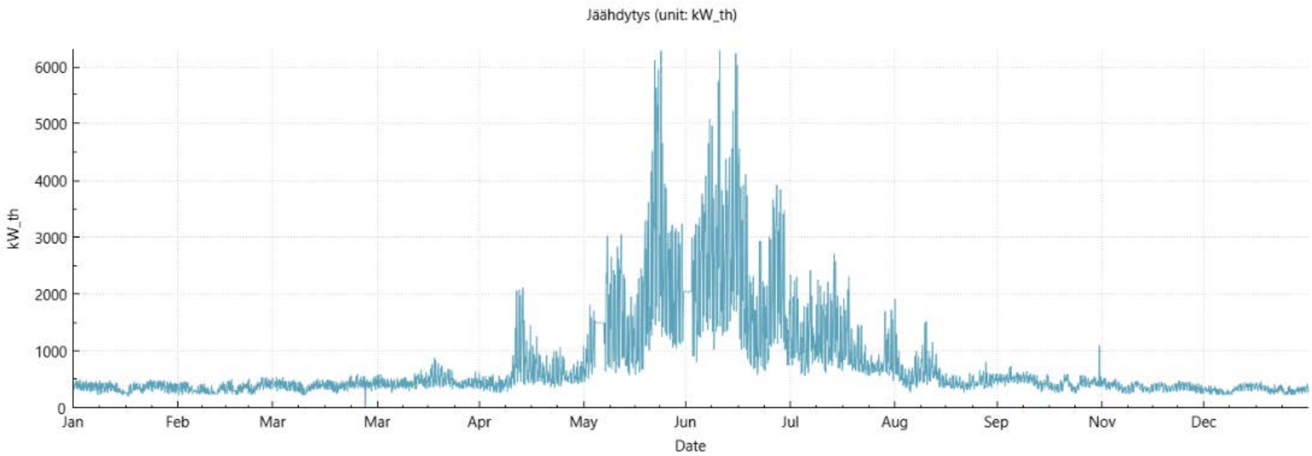

Figure 28. Annual cooling demand. (Source: Siemens)

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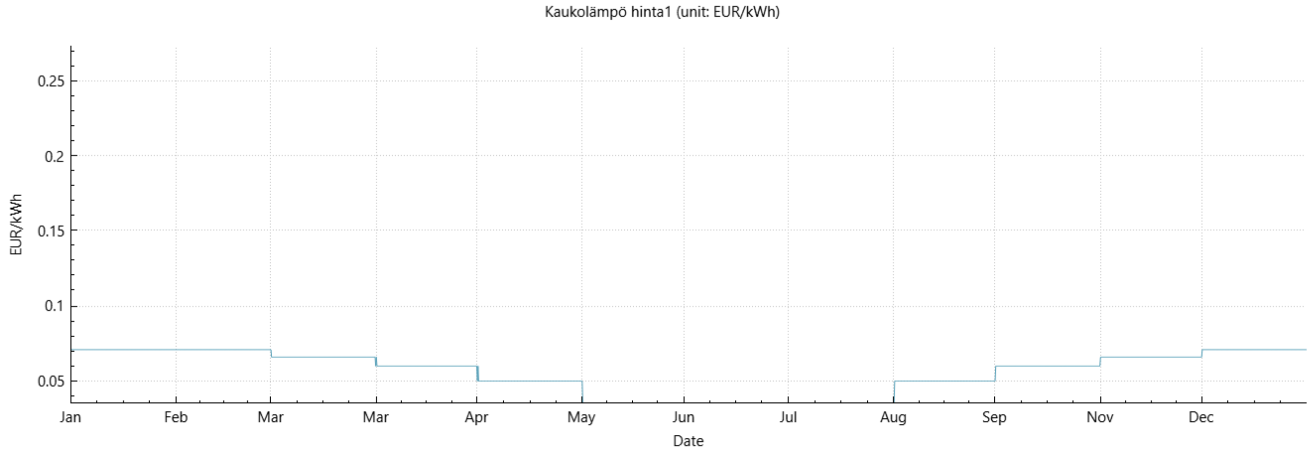

Figure 29. Annual district heating price. (Source: Siemens)

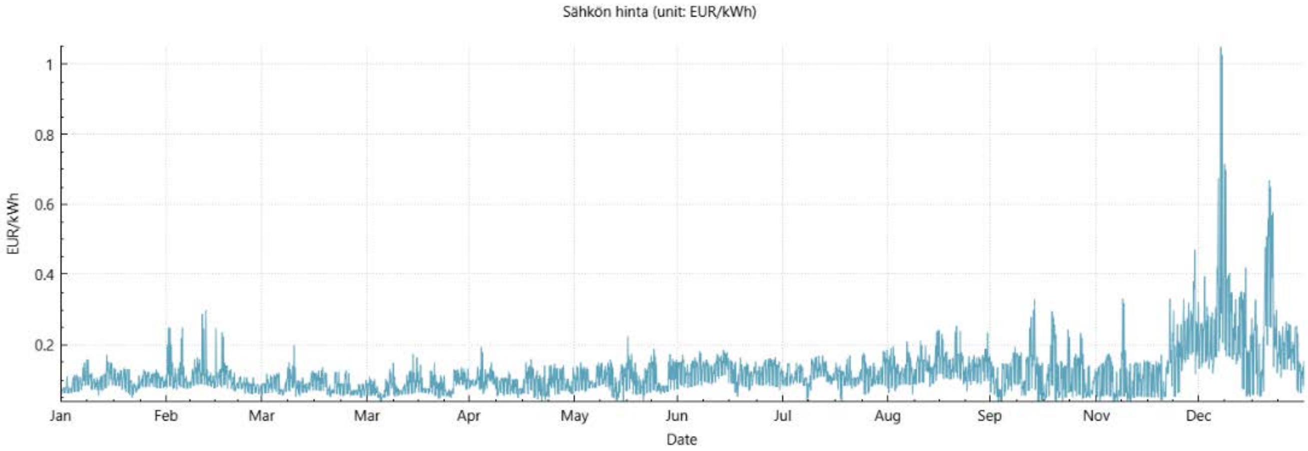

Figure 30. Annual electricity price. (Source: Siemens)

The simulation period was 20 years. And for the first simulation we had one solution and one reference case. The Reference Case was only using district heating for heating and cooling was produced with chillers, that is the current solution in Sello. In the other case we added the deep heat system, which consists of four boreholes that are 1500 m deep each.

According to simulation results, the total cost of ownership in 20 years, of a deep heat system, is 20% less than the Reference Case

3.4 City planning for Positive Energy blocks

Subtask 3.2.3 *City planning for positive energy blocks* is about the development and the planning of positive energy blocks. Actions E10-1 and E10-2 mainly focus on exploring the possibilities to utilize tools (such as the Espoo's 3D city model) in the development and the planning of new areas, but also on how to find energy infrastructure solutions and develop guidelines that enhance the uptake of such solutions. Action E10-3 aims to explore new options for demand side management in Espoo generally.

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On its way to become a modern, vibrant, and sustainable urban district, Kera is being developed together with residents, landowners, companies and other development partners. The networked, multilateral way of working and organising enables better management of complex entities and a better ability to respond to new kinds of competence and cooperation needs than the traditional bilateral approach. Under normal circumstances, commercial utilities would invest in traditional infrastructures such as 3rd generation one-directional district heating at temperatures up to 120 °C. Kera as a testbed proves, that new energy infrastructure solutions for positive energy blocks are already available on the market. To give an example, the energy company Fortum has announced to invest in the construction of an air-to-water heat pump plant (approx. 20 MW) in Kera. The plant will be connected to a low temperature heating network in the Kera area and introduces non-combustion-based technologies in district heat generation. This solution is carbon-neutral as long as the used electricity is procured from carbon-neutral sources, thus advancing Espoo's and Fortum's agreement of a carbon-neutral district heating network by the end of this decade. The heat pump plant will annually reduce the use of coal in other power plants by 106 GWh.

In the past, Kera also functioned as a pilot site for the URBS-data project, which aimed to address characteristic challenges of regional development projects by bringing large amounts of data and entities under control and present them in a clear and visually appealing form that can be examined by decision-makers, stakeholders, and residents. During city planning processes it is common to use 3D models to visualize the new plans and share them with stakeholders and the public. Often architecture companies are providing the models and visualizations for the cities. In the case of Kera, such visual reference plans were recently provided for instance by the architecture office B&M Oy. 3D models are also often used to simulate shading and visualize shading effects between neighbouring buildings. During SPARCS, the possibilities to utilize Espoo's 3D city model as supporting tool in the development of PEDs were explored (see action E10-1 for more details).

Demand Side Management (DSM) is often referred to as a strategy used by electricity utilities to control demand by encouraging consumers to modify their level and pattern of electricity usage. One tool of DSM is Demand Response (DR), which is designed to encourage end-users to make short-term reductions in energy demand in response to for instance a price signal from the energy market, or a trigger initiated by the energy utility. In Espoo the energy company Fortum has developed an artificial intelligence-based control system, which allows for smart controlling of district heating and optimising heat production and the heating of buildings at differing intervals. The smart digital steering system's operation is based on apartment-specific optimization, building level optimization and system level optimization. During SPARCS, the flexibility potential offered by the public building stock for system level optimization was analysed (see action E10-3 for more details).

The following tables include a detailed description of the outcomes achieved related to the SPARCS intervention *E10 – Solutions for Positive Energy Blocks*.

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Action E10-1	City Planning for Positive Energy Blocks. Exploring the possibilities to utilize the continuously updated Espoo 3D City model as a support and tool in the development and planning of the new Kera area.
Detailed plan	• Communicate with city architects and zoning personnel to understand and document the role of the 3D city model in Kera planning. • Map technical, economic and regulatory barriers in piloting innovative PED solutions. • Identify opportunities offered by energy community legislation and new cost-efficient renewable energy generation and distribution technologies • Assess new business models for generation, aggregation, storage and distribution. • Explore the benefits of using 3D city model in pursuing new opportunities and implementing PED solutions • Draft process to mainstream 3D city model support in PED development in Espoo.
Targeted outcome	A mainstreamed process to routinely integrate PED considerations in the early stages of city planning will reduce costs and improve the effectiveness of energy efficiency and distributed energy generation measures in new area development.
Roles and responsibilities	ESP: Main responsibility VTT: Support in identifying technologies relevant to PED development leveraging experiences from similar Lighthouse projects Siemens, Adven, PlugIt, KONE, stakeholders: Propose private sector solutions and new business models for public private partnerships in PEDs
Main achievements till M36	Action E10-1 delivered: • M18: 3D model in city architecture and zoning process documented • M21: Barriers, opportunities and business models assessed • M21: Technical, economic and regulatory barriers in piloting innovative PED solutions mapped • M21: Webinar, focusing on energy communities arranged • In May 2021 the SPARCS project participated in arranging a webinar focusing on energy communities. The event focused on walking through different practical examples of energy communities, with presentations from several Finnish experts. Insights gained during the webinar are contributing to the assessments under action E10-1. • M28: 3D model feasibility in PED implementation assessed • M28: Opportunities by energy communities and business models assessed Infrastructure investments were not required by this action. The achievements are described in more detail after this table.

The role of 3D city models in PED development

3D city models have become common geospatial data assets for cities as they can be utilized in numerous fields and tasks related to e.g. city planning, visualization, and decision-making. As part of the SPARCS action E10-1 the City of Espoo explored the benefits of using 3D city models in pursuing new opportunities and implementing solutions for PEDs. The main findings of this study have been published in the report

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"The role of 3D city models in PED development", which can be found from the sparcs.info webpage (Juslin, The role of 3D city models in PED, 2021). The report not only describes how Espoo's own 3D city model is being used and maintained, but also how the city planning process in general works in Espoo. The report also includes an analysis of the strengths, weaknesses, opportunities, and threats of Espoo's 3D city model. The role of 3D models in the city planning process of the Kera district is covered in a separate chapter.

Technical, Economic and Regulatory barriers for PEDs

PEDs are a new concept to city planners, citizens, businesses, and investors. PEDs can be defined as energy-efficient and energy-flexible urban areas or neighbourhoods which produce net zero greenhouse gas emissions and actively manage an annual local or regional surplus production of renewable energy. PEDs are not only seen as a promising pathway towards sustainable urban areas, but also is their development crucial for the transition towards climate-neutral cities. However, PEDs must still overcome significant hurdles to persuade citizens, residents, city officials, media and businesses.

As part of the SPARCS action E10-1 the City of Espoo assessed technical, economic and regulatory barriers in piloting PED solutions in form of a literature review and a questionnaire. The report includes an overview of the Finnish energy system and effective policies and regulatory frameworks. Furthermore, identified regulatory, economic, as well as technical barriers for the development of PEDs in Finland are presented in the document. The report also includes the results of a short questionnaire about the barriers and prerequisites for the development of PEDs, which was conducted by the City of Espoo in fall 2021.The full report can be found from the sparcs.info webpage (Juslin, Technical, Economic and Regulatory Barriers for PEDs, 2021).

Opportunities provided by energy communities

Energy communities are a social concept focusing on local energy production and distribution, that have gained traction recently due to the move towards more sustainable energy systems. The aim of energy communities is to expand the acceptance of renewable energy by enhancing citizen engagement and social cohesion. In addition, energy communities aim to increase the role that citizens have in the energy transition via expanded funding options.

As part of the SPARCS action E10-1 the City of Espoo examined different opportunities offered by energy community legislation and new cost-efficient renewable energy generation and distribution technologies. The work gives an overview of the existing regulations on energy communities, including a short literature review on existing research networks and projects related to energy communities. The report also contains information about three energy community case examples, which were studied as part of a case study. Lastly, the potential to form an energy community in the Kera district was assessed and presented in the report. The full report can be found from the sparcs.info webpage (Juslin;Mäkinen;& Horn, Energy Communities in Positive Energy Districts - Case Kera, 2022)

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New business models for generation, aggregation, storage and distribution

New innovations in distributed renewable energy generation have increased the options available to consumers, opening the door to new service providers and active prosumers. These new innovations both compete and co-operate with the traditional energy supply system in creating solutions that are both cost-effective and sustainable. This development will continue as the adoption of new technologies accelerates, and the municipalities need to work towards finding solutions that maximize carbon-neutrality while meeting the need to respond to the individualistic needs of citizens and local companies. Municipalities must prepare for the changes ahead and produce an enabling environment for different stakeholders to participate in the decision-making and transformation towards low-carbon communities, while encouraging these new stakeholders to provide new business models, aiming towards a more sustainable urban environment, to the public and private sector.

As part of the SPARCS action E10-1 the City of Espoo assessed possible business models for the electricity, heating, cooling and fuel sectors in the context of the Kera district. Current and new business models were mapped, and the suitability of different models to the Kera area was explained. (Horn & Mäkinen, 2022)

Action E10-2	Energy infrastructure. Planning and on-site follow up of energy infrastructure solutions for positive energy blocks. Solutions enabling energy transfer (consumers as prosumers), including a bi-directional electricity grid and open district-heating network.
Detailed plan	• Identify emerging and established clean energy solutions relevant to Kera, comprising technology, business models and citizen engagement • Assess technology readiness, cost-efficiency, required stakeholder engagement, policy implications and replicability • Develop prosumer models based on new energy community legislation • Assess financial and climate impact of bidirectional electricity and DH grids • Develop guidelines to enhance the uptake of solutions in collaboration with relevant city departments, communities, and technology suppliers, aligning with 3D city model support from E10-1 • Pilot guidelines in development of Kera, Finnoo or other sites • Follow-up on PED infrastructure implementation
Targeted outcome	Adequately planned energy infrastructure improves the availability and feasibility of local energy solutions like waste heat utilisation, peer-to-peer energy markets, aggregation of demand side management and feasibility of distributed energy generation.
Roles and responsibilities	ESP: Main responsibility Stakeholders: Propose additional solutions
Main achievements till M36	Action E10-2 delivered: • M18: Key solutions identified and documented (ref. E10-1: 3D city model assessment for PED completed) • M36: Guidelines for PED infrastructure development completed The achievements are described in more detail after this table.
Outlook (post M36)	M60: Further development of the guidelines for PED infrastructure development; ultimately guidelines to be applied and followed-up in Kera

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In order to establish an energy positive ecosystem in Kera, possible energy solutions and models, as well as foundations for an energy positive ecosystem were studied. Solutions that were identified to have most potential to be implemented in the Kera area are presented in the following Table 4.

Table 4. The most potential PED solutions identified for Kera area.

Local energy production	Energy distribution & measuring	Energy recovery & storage	Services
Solar electricity	Smart electricity grid	Local electricity storages/batteries	Energy as a service
Ground source heat pumps (300m)		Waste to heat	Involvement in DSM
Air to water heat pump		Power-to-X solutions	Virtual Power Plants
Hybrid heat pumps			Local energy exchange
Deep wells (2km)			
Geothermal heat (7km)			

A decision about the main concept to cover Kera's heating and cooling needs was reached. The energy company Fortum has announced to invest in the construction of an air-to-water heat pump plant (approx. 20 MW) in Kera. The plant will be connected to a low temperature heating network in the Kera area and introduces non-combustion-based technologies in district heat generation. The heat pump plant will annually reduce the use of coal in other power plants by 106 GWh. The bi-directional low-temperature district heating network will serve as an innovative base for the further development of local energy solutions. The new heat pump station will produce heat not only for the whole Kera district, but also for other districts in Espoo. The heat pump will use outdoor air as well as waste heat as heat sources. The required electricity will be produced from renewable energy sources. The low-temperature district heating network allows to use waste heat more efficiently, which creates a good base for bi-directional heat trading schemes and new business models. The buildings' own combined heating and cooling heat pumps provide cooling – at the same time the condensation heat can be used as a heat source for the heat pump station (Figure 31).

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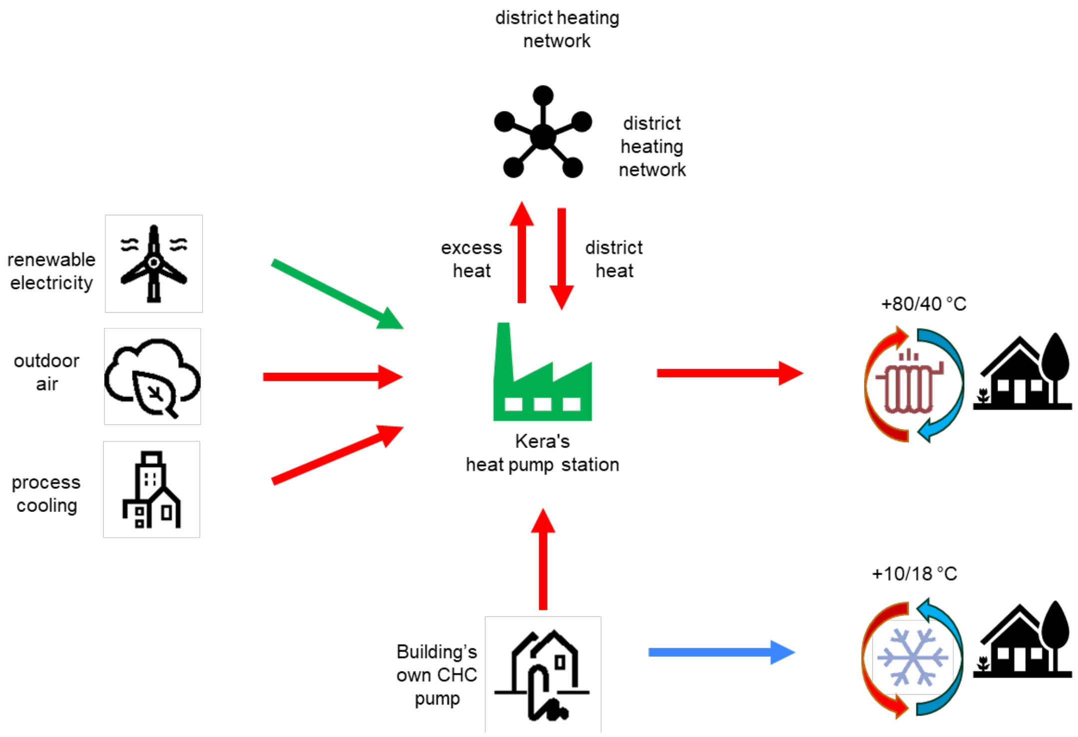

Figure 31. Kera's future district heating/cooling network. (Source: Espoo)

Recently the City of Espoo has been developing guidelines to enhance the uptake of energy infrastructure solutions for positive energy blocks. During autumn 2022 a workshop with Kera's stakeholders and developers as well as different city department representatives was held, and a first version of the guidelines has been drafted. The guidelines will be published under the name "Keran Energian Pelikirja" ("Kera Energy Playbook"). After project month M36, the guidelines will be further developed and refined.

The playbook focuses on different possible energy but also mobility and automation solutions, that can support the development of PEDs within the Kera area. Furthermore, the playbook outlines important steps, that will help companies and other actors to successfully transform the energy system into a carbon-neutral or even energy-positive energy system.

The Kera Energy Playbook builds upon the development commitment for the Kera area, which has been approved as a part of the land use agreement included in the town plan for the Kera centre. The development commitment for Kera is a unique document that steers the development of the Kera area in accordance with Espoo's carbon neutrality and sustainable development goals. The development commitment directs operators in Kera to realise the goals of sustainable development in the long term and lays the foundation for this playbook, which aims to further develop the commitment by guiding operators how to translate the commitment into concrete actions.

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Action E10-3	Energy system planning. The energy system planning explores options for energy demand side management of all buildings by using energy demand response and energy efficiency, as well as acting as heat storage, and enabling the use of emission-free eco heating energy products and services, and demand flexibility.
Detailed plan	• Categorisation of public building stock to reveal low hanging fruits like swimming pools and sport facilities with specific heating and cooling requirements. • List most promising sites and assess thermal energy consumption. • Develop solutions to harness thermal capacity for demand response. • Document results and disseminate results. Related Actions: E16-1 on Espoon Asunnot, E15-1 on 1MW power VPP aggregation in Espoo City properties, E6-1 on digital platforms in Leppävaara and Kera
Targeted outcome	Demand side management reduces peak demand for heating and power. As peak generation units are typically most carbon intensive, annual carbon emissions decrease with added demand flexibility. System-level planning supports the integration of RES and development of 100 PEDs in EU.
Roles and responsibilities	ESP: Identify suitable sites Stakeholders: propose solutions for demand response
Main achievements till M36	Action E10-3 delivered: • M24: A list of most suitable sites for demand response created • M36: Technical solutions for DR assessed and documented • M36: Results were presented to the City's premises department
Outlook (post M36)	M60: Results will be further disseminated within the City of Espoo and to relevant stakeholders

In 2019, the energy company Fortum launched the Smart District Heating pilot project to study the benefits of consumption flexibility, or smart district heating control, in the heating of district-heated housing companies. The study involved 96 housing associations, which started optimising their heating, both at the individual property level and for the benefit of the district heating network. With 275 properties of Espoo Asunnot (Espoo Housing), 4 day-care centres and one school also the City of Espoo has been strongly involved in the pilot of smart district heating control. After the first piloting year, the pilot was extended to around 120 day-care centres and school properties. During the project period from October 2020 to March 2021, the average temperature-corrected energy savings in housing associations was 5.5% compared to the same period in the previous year[2]. Overall, district heating consumption was reduced in 85% of the housing companies. This shows the potential of consumption flexibility to reduce district heating consumption. In terms of indoor temperatures, it was also possible to achieve stable conditions: the temperature in the apartments measured in the pilot

[2] Fortum, "Fortum Älykäs kaukolämpö -pilotin tulokset" na. [Online]. Available: https://www.fortum.fi/alykas-kaukolampo-pilotin-tulokset. [Accessed 05 July 2022].

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sites has been above 20 degrees Celsius 95% of the time. However, no reduction in peak consumption could be demonstrated during the pilot period.

At the moment, there are about 600 buildings connected to Fortum's district heating demand side management system. During SPARCS, and in order to identify more promising sites for demand response, an assessment of the public building stock was conducted. To categorize the public building stock, the thermal energy consumption of city owned buildings was analysed, using the Granlund Manager software and data from recent heating reports.

In total, a dataset including 718 buildings (directly owned by the city of Espoo) was analysed. Buildings of the public building stock can be divided in to 12 building types as shown in the Figure 32 below.

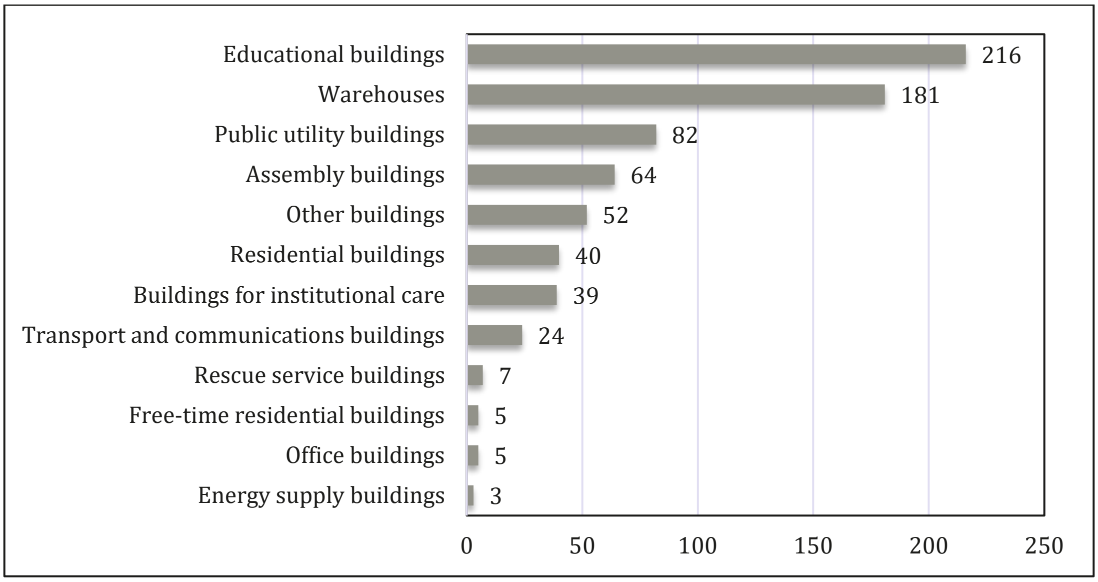

Figure 32:Total amount of buildings by building type. (Source: City of Espoo)

In order to compare different buildings and analyse their thermal energy consumption, the building's energy efficiency (kWh/brm^2) was studied. Out of the 718 buildings however, data about the energy efficiency are available for only 216 buildings.

When comparing the average energy efficiency of different building types, warehouses are the least efficient (average efficiency of 414 kWh/brm^2) and educational buildings the most efficient (average efficiency of 211 kWh/brm^2). When looking at the boxplot below (Figure 33), it can be seen that for some building types (such as e.g. office- and transport and communication buildings) the values are highly scattered. This is due to the low number of buildings within each subgroup.

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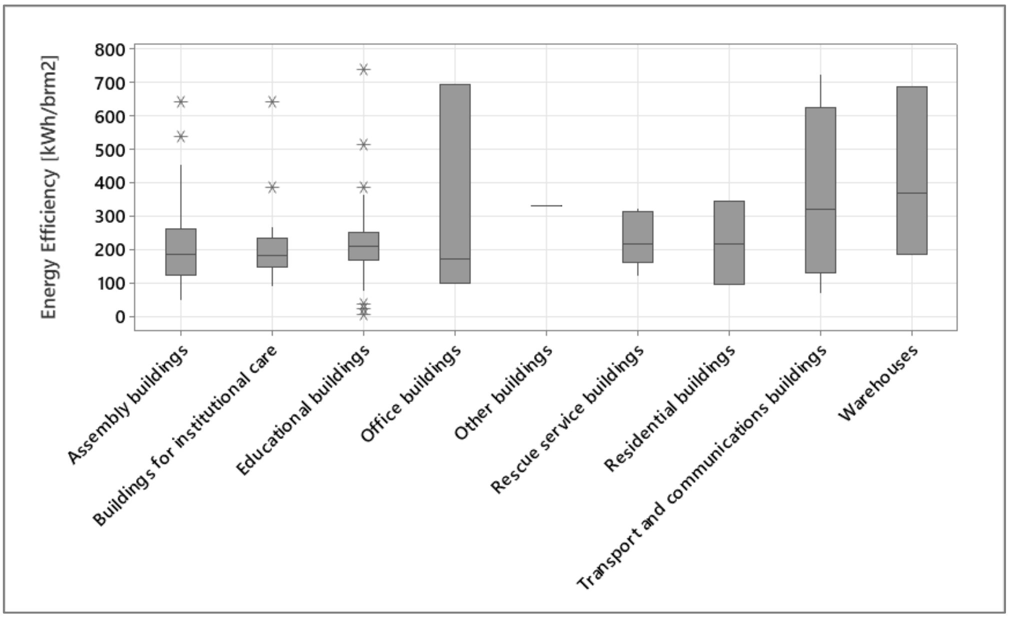

Figure 33. Boxplot of buildings' energy efficiency by building type. (Source: City of Espoo)

While the energy efficiency by building type is as poor as 414 kWh/brm^2 for warehouses, the histogram in Figure 34 shows that there are buildings with an even poorer energy efficiency of over 700 kWh/brm^2.

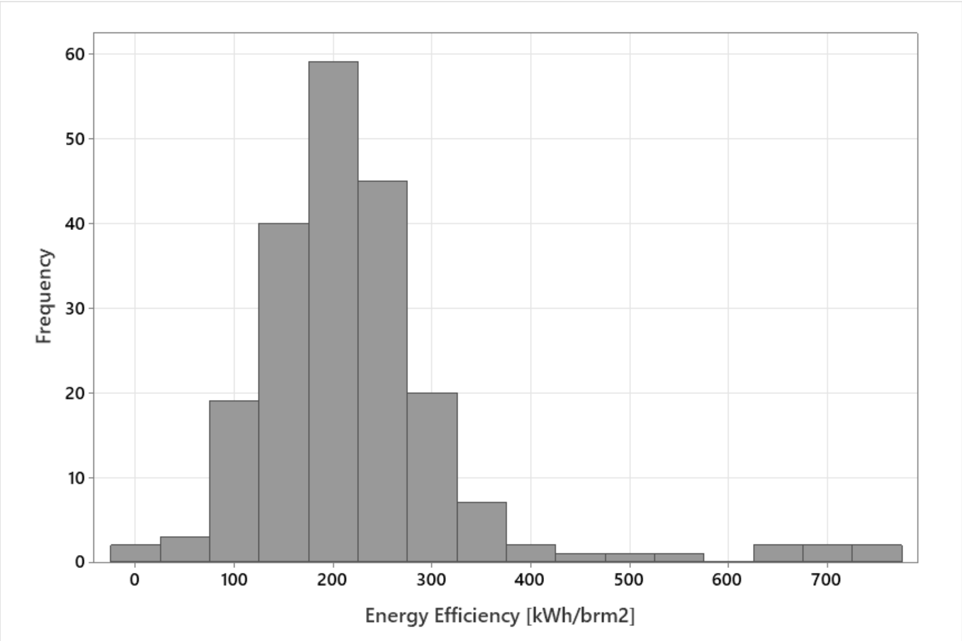

Figure 34. Histogram of buildings' energy efficiency. (Source: City of Espoo)

Additionally, a list of 15 buildings with the poorest energy efficiency was created to examine single buildings in more detail. While the cross area of these 15 buildings varies between 300 m^2 up to almost 10 000 m^2, there is no direct correlation between the size of the building and its energy efficiency.

When comparing the buildings' energy efficiencies, one must assume that the buildings' gross areas are correctly defined. If this is not the case, however, the

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indicated values may be incorrect. The best way to estimate a building's potential for demand response would be by analysing the building's energy consumption over a number of years (preferably on hourly bases). The building's temporal behaviours and its stability as well as anomalies (such as outages, leaks, etc.) could be examined and detected with the help of a large dataset.

The heating report (which was used to conduct this analysis) contains thermal energy consumption data for the month July 2021 as well as the average consumption data from January – July for the years 2020 and 2021. The energy efficiency values are calculated based on the average energy consumption over the last twelve months.

After studying the energy efficiency of the buildings, it was decided to investigate the thermal energy consumption of the selected 15 buildings in more detail. At first, data about the average energy consumption from the last twelve months (2021/7–2022/6) were added to the list of the top 15 least efficient buildings.

It became evident, that the energy consumption of the 15 buildings varies very much compared to each other (from 110 MWh to 6 431 MWh).

When sorting the energy consumption data of all buildings within the heating report in descending order and comparing the values between the years 2021 and 2020, it also became apparent that some of the data cannot be accurate (because of great divergences between the years' consumption values). Therefore, energy consumption data from the complete year 2021 (January – December) were considered, in order to create a new list with the 15 most (thermal) energy consuming buildings. All 15 buildings use district heat. Implementing demand response in buildings that use district heating has the advantage, that emissions in the district heat production can be avoided by providing flexibility. Furthermore, the implementation of demand response or flexibility services for these does not require much effort from the building owner, as the solution is managed by the district heating provider. The owner only needs to ensure the suitability of the buildings heating control systems for remote operation. If the building does not have district heating, the flexibility of the building can still be economically advantageous if the heat source is electric (electric boiler or heat pump). In that case, the building's electricity flexibility can be used to participate in the reserve market. This would require a higher level of expertise on the part of the technical operator of the building.

According to the heating report, 319 buildings are connected to a district or local heating network. 104 buildings are using electricity, 10 buildings use wood, and 27 buildings use light or heavy fuel oils for heating (see also Figure 35). The City of Espoo plans to get rid of all oil-heated buildings by 2025. 656 buildings are listed to have no heat source.

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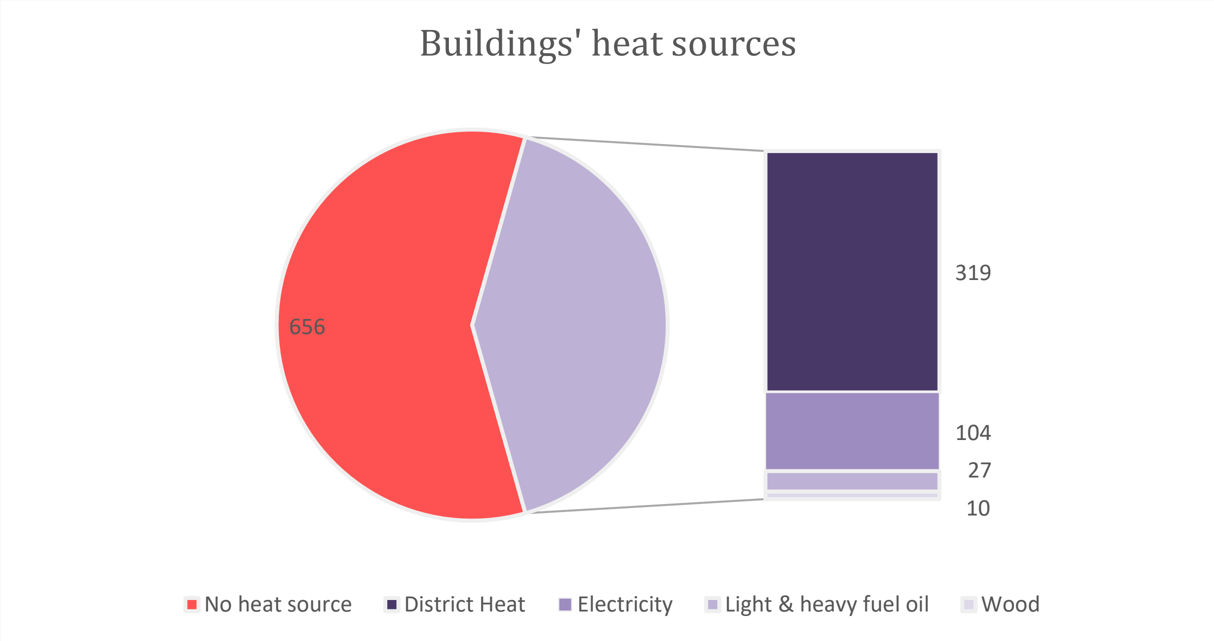

Figure 35. Heat sources of the public building stock.

The results of this assessment were summarized in a separate report, which was presented to the City's premises department. The report also contains several recommendations for future research and actions.

3.5 City scale smart heating and thermal demand response

Smart and sustainable district heating holds great potential to reduce emissions. Compared to other heating options, district heating not only enables energy recycling but also energy storage through the district heating network. District heating systems are an irreplaceable flexibility element for the new energy system. They provide flexibility not only with power-to-heat storages but also by optimizing the heat usage and production. Artificial intelligence- driven district heating together with demand side management (DSM) play and important role in the climate challenge and help shaving thermal peak loads and save emissions.

Within SPARCS the subtask 3.2.4 *City scale smart heating and thermal demand response* extrapolates existing DSM activities to promising subsets of the city's building stock.

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Action E16-1	**Buildings demand side management and demand flexibility. The aim is to implement demand side management to achieve demand flexibility on large scale in both public and private buildings. Solutions based on emission free district heating. Espoo Asunnot Oy (Espoo social housing company) has already connected all its 15,000 apartments to demand response and eco heating. During SPARCS, the solution is further developed and replicated. The development of energy efficiency and energy consumption peak loads are monitored to optimize the city level energy system.**
Detailed plan	• Assess DSM scheme for Espoo Asunnot in terms of heat demand, peak load and emissions reduction. • Assess additional energy efficiency and distributed energy generation potential. • Investigate potential to replicate around Espoo. • Prepare plan and guideline to replication. This task is closely linked to electricity DSM in Action E15-1.
Targeted outcome	Demand side management reduces peak demand for heating and power, presenting an opportunity to reduce capex for distribution infrastructure. As peak generation units are typically most carbon intensive, annual carbon emissions decrease with added demand flexibility.
Roles and responsibilities	ESP: Document buildings and heat demand under DSM VTT/Fortum: Estimate carbon emission reduction potential Siemens: Propose technical approach to optimise DSM
Main achievements till M36	Action E16-1 delivered: • Past energy consumption of Espoon Asunnot building stock has been statistically analysed • Heat demand response behaviour of selected buildings was explored from obtained data covering years 2019-2021 • Preliminary avoided emission values were calculated • Results were presented to Espoon Asunnot and follow ups were planned
Outlook (post M36)	• Following of energy consumption of selected buildings continues • Replication planning to be continued in cooperation with Espoon Asunnot and Fortum

In their latest yearly report Espoo Asunnot reported that almost their entire real estate is already connected to the Leanheat heating optimizing system (Espoon Asunnot Oy, 2021). With the help of the optimizing system Espoo Asunnot has been able to time maintenance and repair activities and achieve savings in heating while keeping a constant indoor temperature for their customers. Espoo Asunnot further reports that they have been able to cut district heat peak loads without affecting indoor comfort. By the end of 2021, Espoo Asunnot owned in total 15 879 apartments, which is 155 more than in 2020.

To estimate the amount of emissions avoided with the help of the DSM scheme, a detailed energy and DSM flexibility analysis was performed for 8 selected buildings. The analysis was based on recorded hourly values for the years 2019–2021. The results are summarised in the following.

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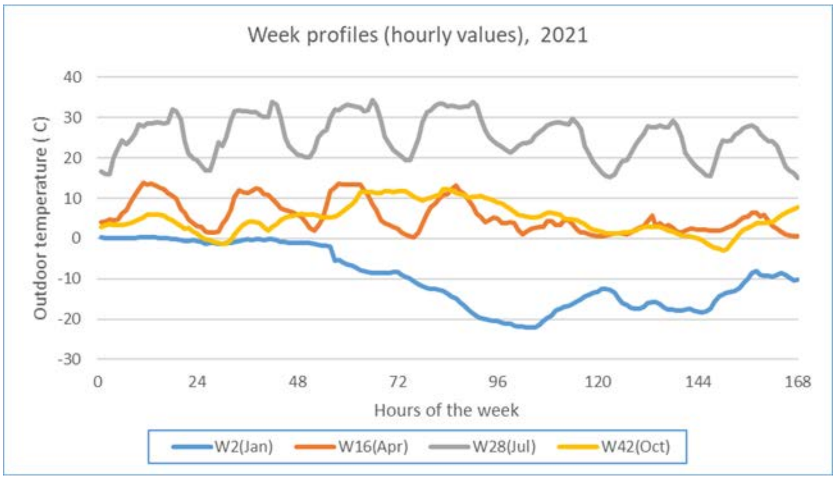

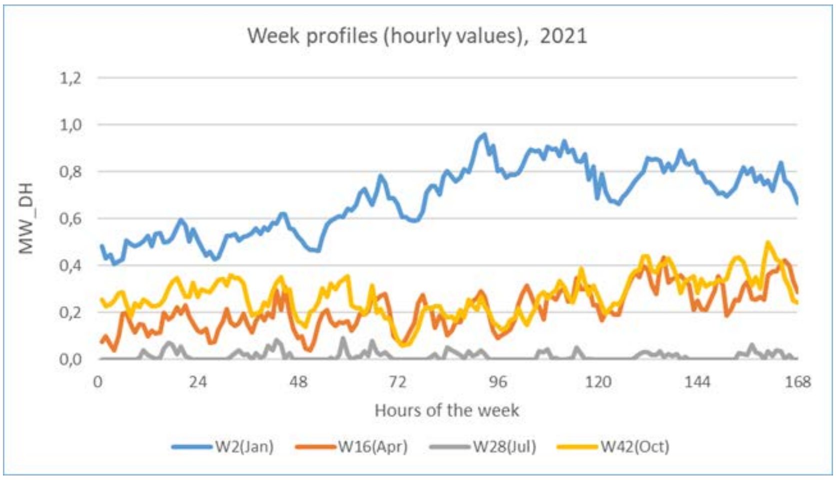

Figure 36. Profiles of Outdoor temperature and aggregated District Heating (DH) consumption in investigated 8 buildings during 4 distinct weeks in 2021. (Source: VTT)

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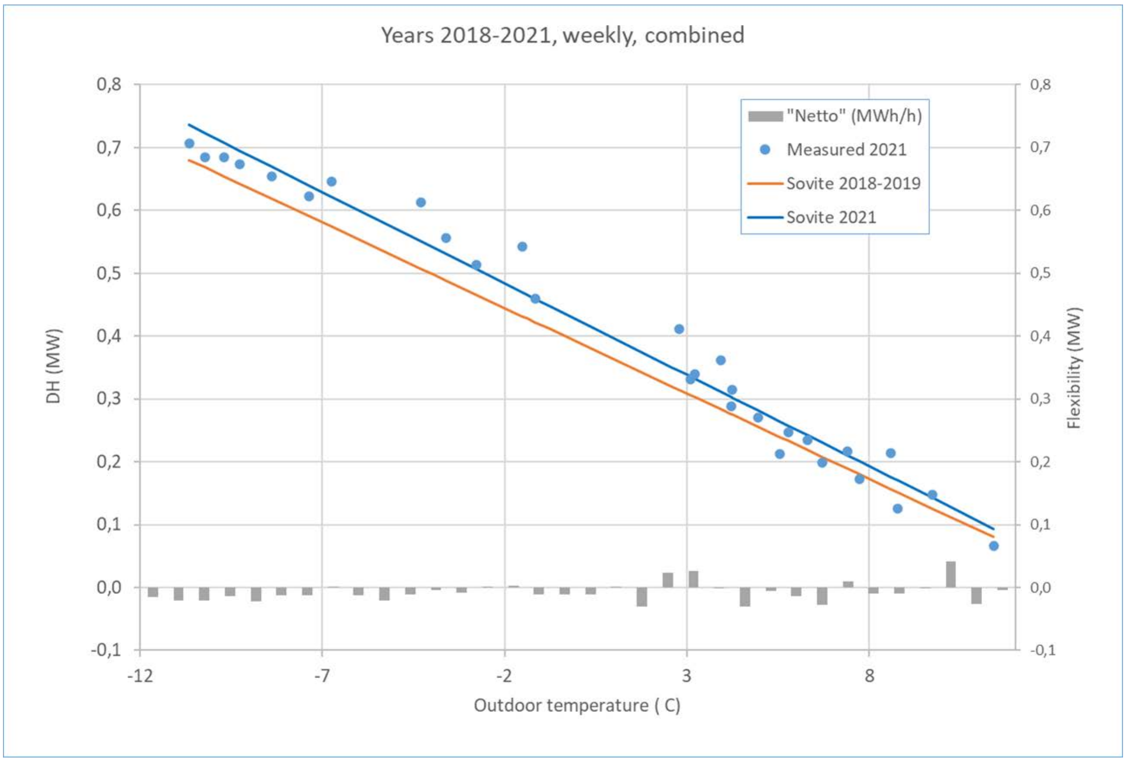

Figure 37. Measured DH consumption and DSM flexibility in investigated 8 buildings. (Source: VTT)

In Figure 37 the measured DH values are displayed by markers and fit curves (values on the left hand axis), while flexibility is displayed by bars (values on the right hand axis).

Aggregated flexibility values displayed by months are presented in Figure 38. The analysis has shown that using monthly values of emission factors (obtained from the energy provider), avoided emission in 2021 due to provided DSM flexibility in the analysed group of 8 buildings was 4470 kg CO_2.

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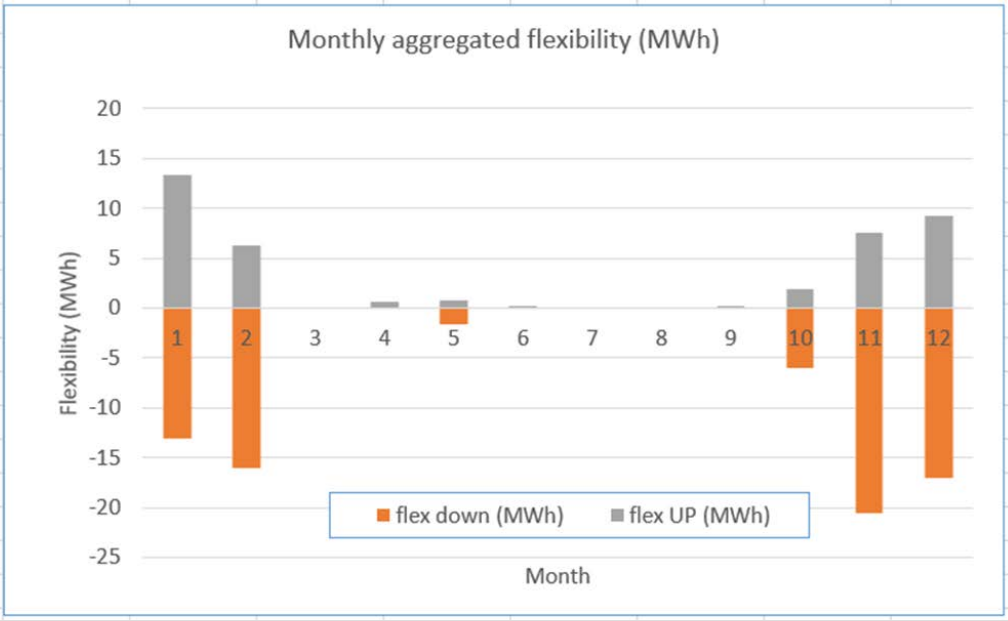
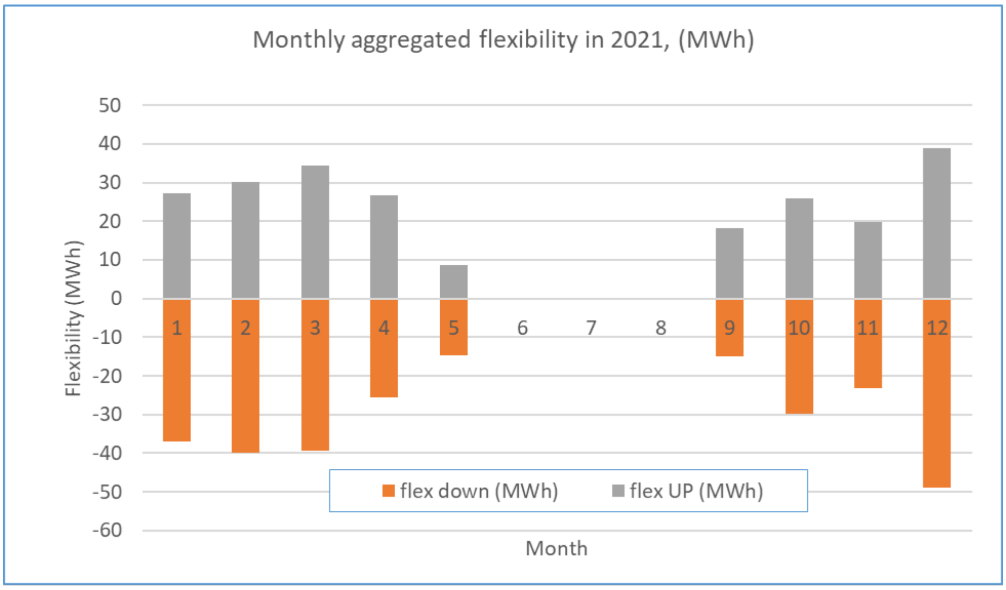


Summary 2020 based on hourly analysis (heating only)

flex down (kWh/m2)	flex UP (kWh/m2)	v. 2020 True value (kWh/m2)	**Measured (kWh/m2)**	"Netto" (kWh/m2)
-2,7	1,5	63,7	**62,4**	-1,3



Summary 2021 based on hourly analysis (heating only)

flex down (kWh/m2)	flex UP (kWh/m2)	v. 2021 True value (kWh/m2)	**Measured (kWh/m2)**	"Netto" (kWh/m2)
-10,0	8,5	100,2	**98,5**	-1,7

Figure 38. Aggregated flexibilities in investigated 8 buildings in years 2020 and 2021. (Source: VTT)

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4 ICT AND INTEROPERABILITY IN ESPOO LIGHTHOUSE DEMONSTRATIONS

4.1 Introduction to task 3.3

The trend towards greater digitalization of energy has been enabled by advances in data, analytics and connectivity. Digitalization can greatly increase the lifetime, efficiency and utilization of energy infrastructure and reduce costs by through technologies that create and gather data at all stages of the energy supply chain and monitor and analyse data before using it to make changes to the physical environment (Sung, 2019). Connectivity helps to couple different energy sectors, so that consumers and producers in any sector can actively participate across energy system operations, which increases the flexibility with which the system can cope with regarding the imbalance of supply and demand, while also reducing the cost of integrating new technologies like distributed generation, energy storages and electric vehicles.

The EU is moving from centralized electricity generation in power plants operated by large utilities towards a mix of decentralized and often renewable energy production in small facilities (Bruegel, 2019). This change in energy sector combined with electrification of mobility and heat creates a new challenge to power grids. Virtual Power Plants are a critical element in this transition and are enabled by digitalization.

A Digital Twin allows a connected, digital representation of a building and of ongoing processes in the building. It brings together dynamic and static data from multiple sources in 2D/3D models and enables informed and effective decisions making. It bridges the physical and digital worlds through sensors that collect real-time data within the physical environment. It provides real-time understanding of how a building is performing – enabling immediate adjustment to optimize efficiency and to provide data to improve the design of future buildings. The result is a more cost-effective, straightforward and sustainable smart building.

The energy sector is expected to benefit from blockchain technology. Blockchain enables innovative platforms that help the buyer find all available renewable energy resources and make direct purchases, thus accelerating the transition to low-carbon energy and expanding access to clean energy markets for all. Distributed energy resources will play a valuable role providing grid services, such as helping to balance supply and demand in flexibility market. Blockchain technology can make it easy for distributed energy resources to participate and get compensated for delivered grid services.

Decentralized and complex energy systems require also fast communication with high capacity, bit rate, throughput, latency and energy efficiency and resilience. 5G networks are expected to provide the communication requirements for the new decentralized complex energy systems.

The objective of task 3.3 is to enable sector coupling and increase the interoperability, monitoring and control of various energy systems by ICT between smart buildings, smart grid and district heating and cooling systems, EV charging infrastructure, and the allocation of open data.

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Task 3.3 Includes following subtasks:

- T3.3.1 Virtual Power Plant for optimized RES energy use (presented in Section 4.2)
- T3.3.2 Smart energy services (presented in Section 4.3)
- T3.3.3 Smart Building Energy Management (presented in Section 4.4)

4.2 Virtual Power Plant for optimized RES energy use

A Virtual Power Plant is a pool of several small and medium scale installations, either consuming or producing electricity. When small and medium scale installations are integrated into a Virtual Power Plant, the power and flexibility of the aggregated assets can be traded collectively.

In this subtask, Sello's multipurpose center Virtual Power Plant platform is utilized. Sello is buying power from Nordpool and is locally producing energy with PV (750 kWp). Sello's power system includes microgrid functionality with integrated electrical equipment, mostly HVAC and stationary energy storage (2 MW and 2.1 MWh). Microgrid functionality enables Sello to participate through Vibeco Virtual Power Plant in electricity reserve markets operated by Fingrid. The system is visualised in Figure 39 and Sello's power usage is shown in Figure 40.

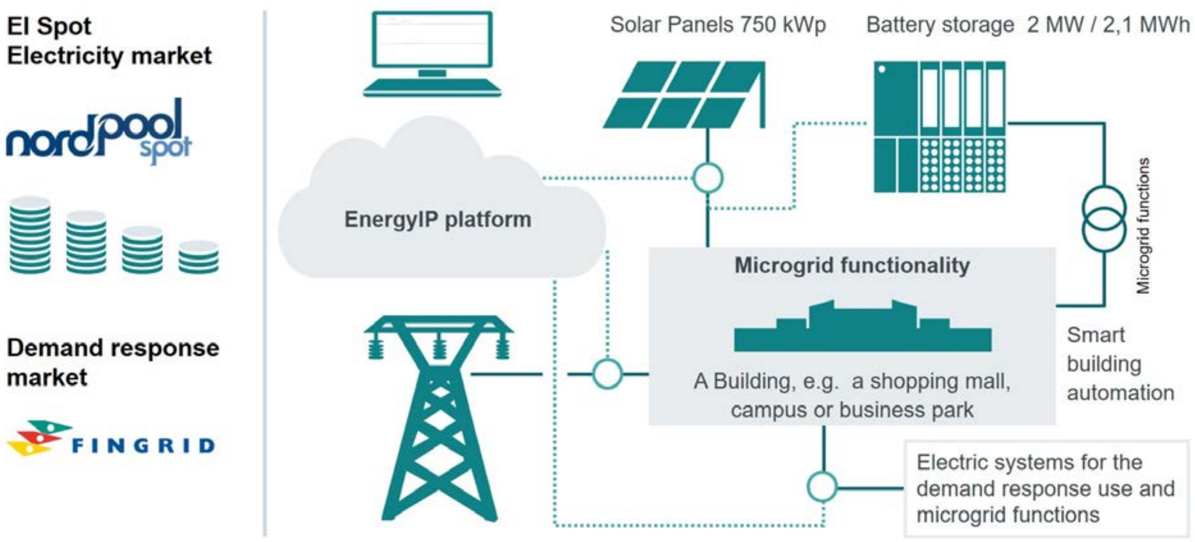

Figure 39. Sello's smart energy system. (Source: Siemens)

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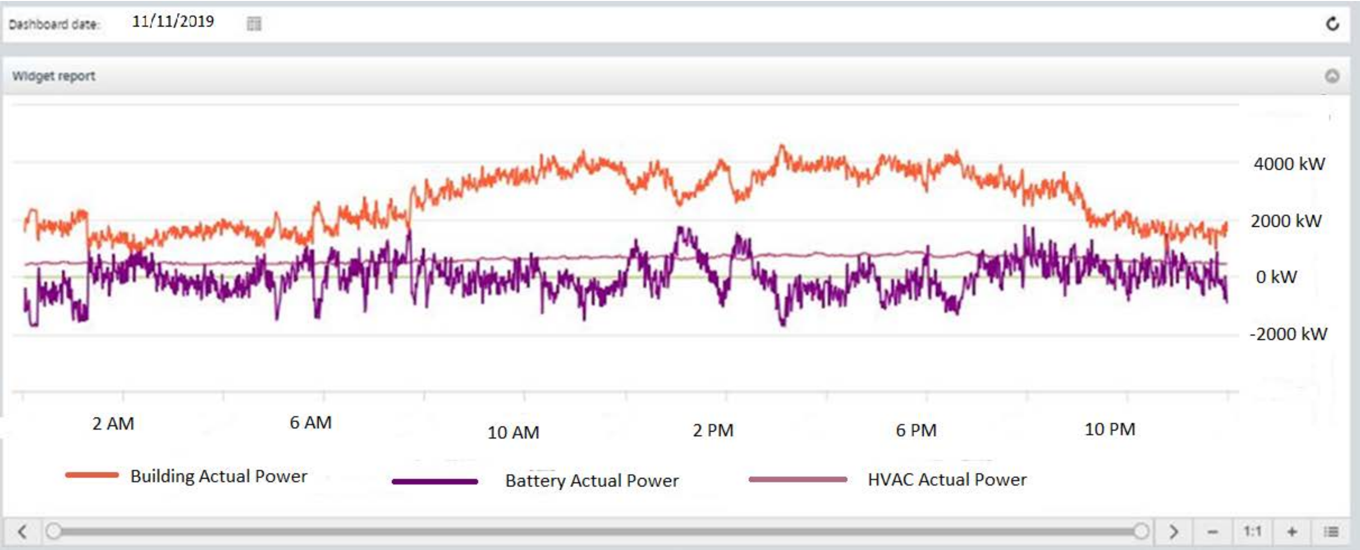

Figure 40. Sello's power usage during a normal weekday. (Source: Siemens)

In Action 17-1, Digital twins can be used to replicate the physical and operational characteristics of a power generation plant or other utility asset prior to construction and also to help improve operations and maintenance over the useful life of physical installation.

Some of the key goals of the digital twin are cost savings, increased revenue, reduced outages, improved operations, and managing market dynamics.

Virtual Power Plant connected assets are optimised based on a self-learning algorithm to increase the flexibility potential of each asset. One of the major issues of optimising a Virtual Power Plant is the lack of standardized semantic descriptions of the physical, logical and virtual assets. In this subtask a data model is tested on the Sello block. The Action also includes creation of a BIM model of the Sello block that will be used in the creation of a Digital Twin in Action E17-1.

In Action E15-1, public entities are the forerunners in achieving carbon neutrality. Buildings are responsible for 40% of CO_2 emissions in the world. Thus, new solutions for energy-efficient buildings and operating models need to be developed. One of these solutions could be connecting buildings to a Virtual Power Plant that enables them to become an active part of the power system. The flexibility potential of city owned assets is evaluated, and according to this information chosen buildings are connected to a Virtual Power Plant. In addition, the reduction of CO_2 emissions is evaluated. In action E15-2, the use of blockchain technology for supporting Demand Response (DR) and Virtual Power Plant (VPP) solutions is evaluated. Blockchain could be a cost-efficient, secure and reliable way of enabling peer-to-peer transactions between energy prosumers within a more decentralized energy system, and in enabling new demand response solutions. These aspects are investigated in a feasibility study within the action.

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Action E6-1	Improving the prediction of the energy performance, both heat and electricity, and the predictions for energy market participation for Sello block based on data collected nearly in real time and stored historic data pursuing the Virtual Power Plant (VPP) operations. VPP considers Kone's elevators energy control, optimal use of local PV generation, electricity storage, air conditioning, lighting and emergency power systems. Introducing peak-load management, artificial intelligence technologies.
Detailed plan	• Define solution architecture • Integrate real-time data from selected Sello elevators, escalators and moving walks with the Siemens platform • Integrate Sello's energy data via API to VTT • Create self-learning algorithms of Sello's energy performance (1st version available for heat and electricity, for both consumption and PV production) • Develop the prediction algorithms until prediction and actual are sufficiently close enough (1st version available) • Provide control strategies via prediction algorithm to increase flexibility towards TSO and improve energy performance Additional, if resources are available: • Integrate prediction algorithm (Digital Twin) to Sello energy management system via APIs • Creating a BIM model (ifcSpace) of a Sello block • Integrate the prediction model to Digital Twin model via APIs to visualize the energy performance • Visualization of energy performance
Targeted outcome	Creating a prediction model based on real time data of Sello blocks energy performance to increase the energy performance of a Sello block and flexibility towards the TSO. Create a co-operation model beyond SPARCS.
Roles and responsibilities	SIE: Provide historical and real time data, provide BIM model, supporting in developing self-learning algorithm VTT: Develop self-learning algorithm, link data to BIM model and develop KPIs KONE: Provide refined data of selected elevators, escalators and moving walks.
Main achievements till M36	Action E6-1 delivered: • System architecture defined • VTT prediction model (first iteration) includes Sello's next day predictions for electric cars charging power and PV based local electricity production completed • Integration of prediction algorithm to Digital Twin completed • Developed data model for Sello's Building automation data (SIE) • First version of self-learning algorithms for energy consumption and the production of PV panels is available online (VTT) • Data integrated from Siemens systems to VTT. First version of data model done. • KONE elevator group short-term power demand forecast algorithm developed, tested, and running in Sello. Communication established with

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	the Siemens platform. Performance monitoring on-going. (actions depicted in detail under action E6-3) • SIE: Sello 3D Scan from technical rooms done and visualized in 360 viewer. • SIE: Developed BIM model for Building Automation devices • SIE: Degree Thesis BIM-model creation for existing buildings from the perspective of automation • SIE: Sello Energy Usage Anomaly Detection algorithm done • SIE: Sello Energy Manager setup to visualize energy consumption • SIE: First versions of Sello Asset Flexibility / Market prediction model done Iterate Sello Asset Flexibility / Market prediction model development ongoing

Integration platform

In Sello building automation and energy data is shared between parties by Siemens Navigator HTTP REST API which provides time series data from selected points. Data is updated to Navigator periodically from different systems and integrations allow continuous updates for building data. The data is used for prediction algorithms and other demos done in this project that need real data from the Sello shopping center energy and building automation system. For Controlling the building, the data need to be written to Desigo CC which also provides HTTP REST API. This would also provide real time data, however the Desigo CC API is not opened to all parties as it has direct effect on working of the building automation system and periodical polled data from Navigator was enough for these use cases.

Data modeling

Data models for building automation data were researched in this action to help with making data more usable and having more context for the data in machine readable form, which would allow creating more intelligent, scalable, and interoperable programs that would not need manual mapping of data between systems.

Graph models were selected for more extensive tests as they enable easy and fast querying and are also building blocks for new Siemens products. Graph models describe the relationships between nodes. In our Graph nodes, are for example field controllers, physical measurement points or virtual points representing the point in another program. Relationships have names that describe the relation. Relationships are one way relations, but there can be relationship made in both directions. In Sello we created Graph model from building automation BACnet network scan. This graph was then extended to include data from other Siemens systems: the Cloud based advanced analytics platform Navigator and Building Management platform DesigoCC. This allows querying data between systems and finding the matching point in different connected systems. This reduces the need for manual mapping of points for each project and program that could take a long time and would prevent scalability of program. Also, other standardized modeling projects like Project Haystack were researched and we would see value in adding them to graph model as well, but this wasn't done for this project due to added systems were already deemed enough for allowing us to test the idea.

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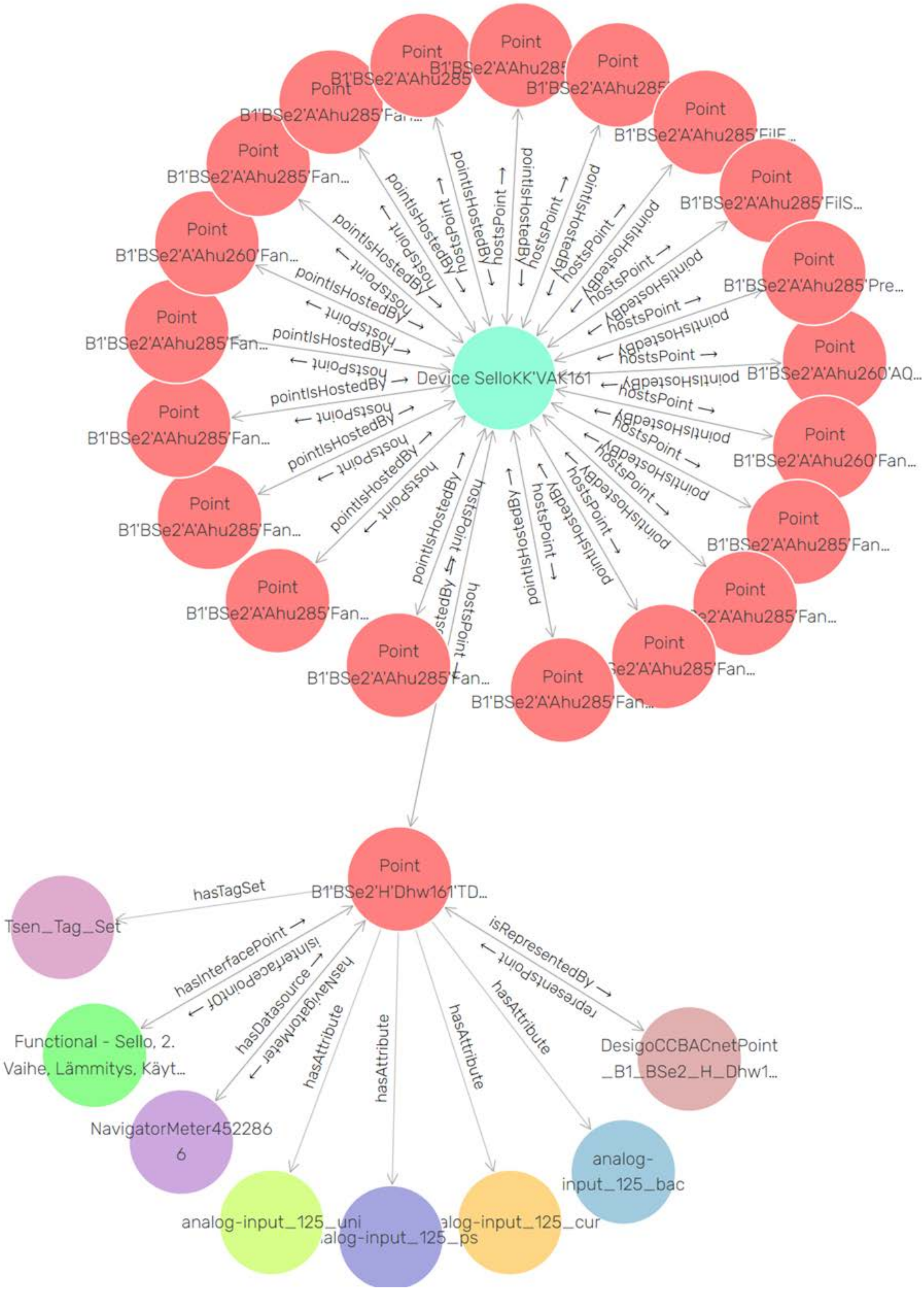

Figure 41. Part of created graph model for Sello building automation. The picture shows relationships between field controller devices, BACnet points and BACnet point's variables. Visualised in GraphDB program. (Source: Siemens)

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4.2.1 Sello BIM model and point cloud

A Building Information Modelling (BIM) is an important aspect of efficient energy and facility management in buildings, and its growth in popularity is ever increasing. The whole building life cycle offers extensive usage opportunities for BIMmodel. By having real life look into the building we can for example share more accurate knowledge of the building and its systems remotely and can plan future renovations and other changes first digitally. The modelling of new buildings is done before construction begins. Modelling existing buildings is more challenging, since it includes data acquisition, data processing, object recognition and the modelling itself. The purpose of this actions was to explore the creation process of BIM models, and their utilization potential in building automation.

For Sello, the first architecture BIM model was done from drawings of building, later a 3D laser scanned point cloud was created from selected technical rooms in Sello. The point cloud was then connected to the Architecture BIM Model and they were combined together to help with creating BIM model from Building Automation devices, which didn't have good up to date drawings. This enabled BIM model to be modelled with enough accuracy for existing building without good drawings and be built by people who were not familiar with the building and didn't have physical access to the building.

Deeper look into creating BIM models for existing buildings was done in Degree thesis made by Siemens Working Student with topic "BIM-model creation for existing buildings from the perspective of automation".

BIM models created by designers of different systems can be shared between participants and used together to create fuller model with multiple different systems.

Figure 42. Sello BIM Models and point cloud scan together. (picture: Siemens)

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The new Siemens Building X Platform was taken in use at Sello site with a 360° Viewer app which utilizes the created NavVis 3d Laser scanned point cloud and enables exploring the building and taking accurate measurements from the created 3D environment. Which gives real look how the building is built and we can see if there has been deviations from the BIM model and give familiar look of the building virtually in addition to the modeled version. Measuring can also be used in fitting new machines, furniture or other objects to the place. Also the Building X Energy Manager app for energy monitoring was taken into use.

To find irregularities in building energy usage an in-depth data analysis was done for Electricity, Water and Heating meters to look for anomalies and root causes in consumption of these mediums. Effects of outside temperature, holidays and occupancy data were taken into account. The project was done with historical data, where underconsumption during covid lockdowns and overconsumption during heat waves in Espoo was noticed. Other anomalies were scrutinized and work continues to better find out the real anomalities and root causes for them. This data is then used as help to fix these root causes and improve the energy usage of the building. One area was to find out the effect of occupancy on the electricity consumption. When comparing occupancy data to the electricity consumption data it was noticed that the occupancy affects the consumption but the effect of occupancy becomes negligible during summers, where temperature becomes the major driving factor for the consumption. This could primarily be because of excessive energy being consumed for cooling/ventilation needs. This is evident from the increase in correlation when neglecting peak summer months data.

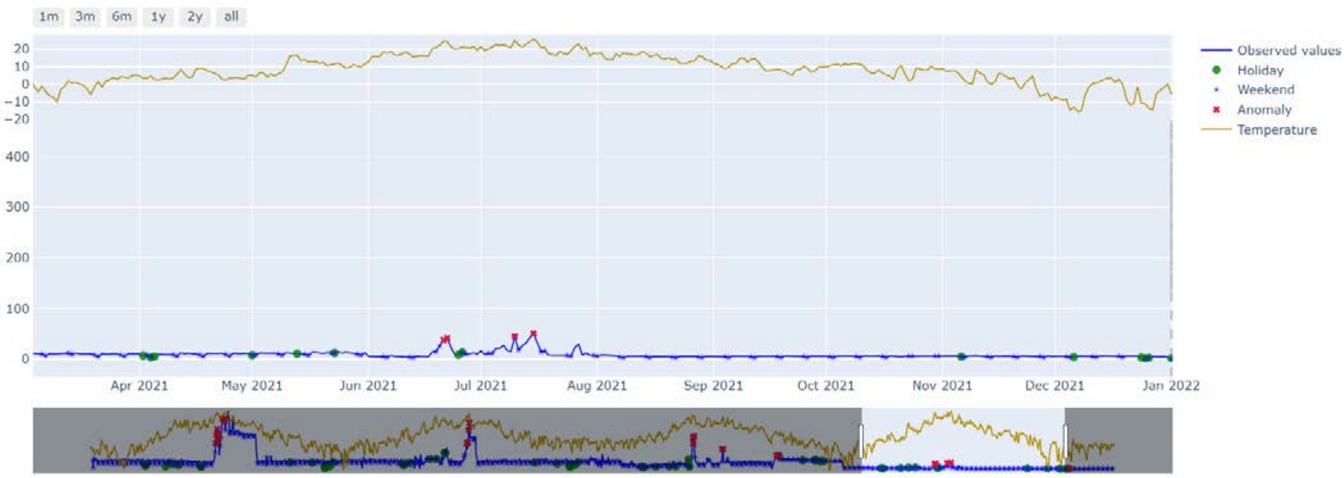

Figure 43. Sello Energy usage and anomalies compared to outside temperature. (Source: Siemens)

4.2.2 Sello Flexibility prediction

The three targets "flexibility down", "flexibility up" and "instant power reference" are forecasted with a prediction horizon of 24 hours from a seven-day history of those three time series together with temperature and holidays as provided external data /

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forecasts (both history and future values are provided for temperature and holidays) and some synthetic helper series for time of day, time of week and time of year.

The “instant power reference” output is not a requested model result, but the model uses a forecast of it internally anyway and it is useful as a sanity check reference.

In Figure 43 the red vertical line marks the present point in time. Predictions on validation data are shown in magenta – these are all part of a validation data set that the model has not seen during training. They are shown to test generalization capabilities of the model. Actual values are shown in in brown and the first day that isn't part of the history horizon anymore is highlighted in blue. All plots always show all predicted days in an eleven-day window, so if several days in the validation dataset are less than eleven days apart, these are all shown in the same graph.

Qualitatively the predictions are in most cases reasonably close to the real values. Sometimes the flexibilities and reference values turn out lower than the model predicts though. Generally, some small fluctuations aren't predicted, the forecast curves are usually smoother than the real occurrences. Both observations appear plausible as there is no indication in the data that would correlate with these microstructures or lower-than expected values, so we would need further correlated inputs that give the model a chance to predict those.

Test-wise we added occupancy of visitors in the Sello mall as additional input (only as past data). This value correlated enough that it was considered relevant by the training to get slightly better forecasts in some cases. In other cases, it threw off the forecasts completely – there is no indication when the value correlates positively or negatively. In the end we decided to take occupancy out again to get more reliable predictions overall.

We think the Sello forecasts look practical enough that they can be used for iterating on the end-to-end process and user experience. If further relevant inputs become available, we expect to be able to improve forecast accuracy further.

4.2.3 FCR-N Market Price Forecast

At first we assumed that the normal market price is bound to the situation of the overall electricity distribution network. Energy availability should play a role as well as market mechanisms that are observable e.g., in the spot market prices. Together with volume information and other more indirect indicators in the market and time dependencies like daily, weekly, and maybe even seasonal rhythms we expected that the prices for the normal operation control market are predictable.

Reason for predicting market price is to be able to decide in which market the asset flexibility should be offered and at what price so that they would be accepted. Prediction algorithm was created to lower the needed manual effort and increase the accuracy in the process.

We built models with several different data series combinations from the available data. It turned out that many models are unstable, and the stable models were only able to predict a rough estimate of an average price level.

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We observed in the data periods where the price stayed almost constant and other periods where huge price peaks appeared seemingly out of nowhere. A deeper analysis of the situation was in order.

A good measure for the potential usefulness of a variable is Mutual Information. Mutual Information is a way to measure how much information about a variable (e.g., one of our time series) can be gained by observing another variable (time series). In contrast to measures like correlation this also is useful to detect non-linear dependencies. With such an analysis time dependencies are not regarded. We will come to such dependencies later.

A mutual information estimate of our available time series already shows some of the the main difficulties:

Table 5. Mutual information with target 'Fingrid_norm_price_hourly_value':

Data Series	**Mutual Information**
Hydro_Reservoir_GWh_SE	0.4554
Hydro_Reservoir_GWh_NO	0.4392
Hydro_Reservoir_GWh_FI	0.4340
Hydro_Reservoir_GWh_nFI	0.4328
Fingrid_norm_foreign_trade_value	0.4218
Unavailable_FI_Loss	0.3521
Fingrid_norm_yearly_plans_value	0.3187
Fingrid_norm_market_volume_value	0.2890
Espoo_Temperature_value	0.2023

The highest relationships are shown with the state of the hydro reservoirs. These are weekly values and might be useful to get an estimate for general price levels but do not vary over a week. The relationship with foreign trade value is clear because it documents an aspect of the normal operations market but there is no relation useable in a forecast. We see e.g., that when the foreign trade value goes up, the local price goes down, but this happens at roughly the same time and is itself not better predictable than the price itself. It is also easily explainable if we look at the bidding process. More foreign trade means that less of the local bids are activated so the bids with higher prices are left out.

The relationship with outages is also expected and it could be interesting to reduce the outage data to the planned outages for a later experiment. Also, a distinction of the observed plants into ones that provide base level energy and others that may take part in control schemes (e.g. gas turbines) may prove helpful but the dependency is rather weak and the effects here are as long term as the fill levels of hydro reservoirs. These dependencies are not useful for short term forecasts.

Market volume data is just another view of the network state being related to the price data but not useable for forecasting because it only describes the same market state using a different observable variable, as we already saw in the foreign trade values.

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The semantics of the yearly plans data is not completely clear yet and should be discussed but experiments also show no directly useable relations.

Experiments with feed forward models as well as recurrent models unfolded in time showed no qualitative difference between the two modelling approaches. Different mechanisms to introduce temporal dependencies were tried (large sparse propagation and LSTM variants) but none of them was able to uncover helpful dependencies in the data.

The models for forecasting real price values were so unreliable, that we switched to models forecasting price differences and using differences as inputs also. This eliminates drift effects and we expected to see effects that make at least price changes better predictable. A mutual information analysis showed:

Table 6. Mutual information with target 'Fingrid_norm_price_hourly_value_delta':

Data Series	Mutual Information
Fingrid_norm_price_hourly_value_lnq	0.7610
Fingrid_norm_market_volume_value_delta	0.3737
Fingrid_norm_foreign_trade_value_delta	0.3068
Fingrid_norm_price_hourly_value	0.1170
Fingrid_norm_foreign_trade_value	0.1060
Unavailable_FI_Loss	0.09095
Fingrid_norm_yearly_plans_value	0.07601
Fingrid_norm_yearly_plans_value_delta	0.07448
time_of_day	0.07307
Espoo_Temperature_value	0.07190
Fingrid_norm_market_volume_value	0.07099

The first strong relationship with the logarithm of value quotients of neighbouring time series values is expected. This is still the same time series with only a different preprocessing.

As before we see here a strong relation with market volume and foreign trade. Outages play a role. We also see a weak relation with the time of day. Finally, there is also a weak relation to temperature. We see that only the weakest relations provide qualitatively different information than the observations of the market itself.

Looking for additional data one might be interested in the actual measured network frequency. As this should be bound to the activated market volume, we do not expect additional information from such a time series.

We also looked at relations with different spot markets, but the FCR-N market seems to be mostly decoupled from the spot market. This is probably due to the completely different way in which flexibility is available in contrast to planned energy production. We will come to this later.

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It appears that the currently available data does not give enough hints for a reliable day ahead price forecast.

We tried autoregressive models next, which attempt to detect a pattern in the daily, weekly, or even seasonal developments. Also, these models did not help because there can be seen several quite different daily patterns which are only observable over a few days at a time and our models could not find dependencies that would allow us to select the right pattern for a day.

Examples:

- 2021-04-04 almost constant prices
- 2021-05-19 strong afternoon fluctuations
- 2021-07-10 price increase a few hours before midnight with strong reduction in the early morning hours
- 2021-10-17 strong price oscillations in the evening

There is no discernable weekly rhythm and no stable recognizable daily pattern. We see two possible explanations for this market behaviour. One may be that the market consists of actors that are themselves new to this specific market and consistent market patterns still must develop. The other explanation is that we are simply looking at the wrong data. Our initial hypothesis was, that this market is somehow bound to the typical energy market mechanisms like e.g., prices in energy spot markets.

This may be a misunderstanding. An alternative hypothesis is, that the FCR-N market is actually bound to the available flexibility. Prices could go up if the flexibility forecast is low and go down if the flexibility forecast is high. This would reflect the risk in participating in the FCR-N market which is naturally independent of the typical energy market mechanisms but is instead influenced by local energy demand patterns. Also, lower flexibility could lead to more expensive offers to be accepted in the FCR-N market to offset the reduced volumes and we would therefore expect higher prices and (due to the bidding process) also higher price volatility.

A counter argument is here that in this case it would be expected that clear daily patterns should be observable like the ones that can be seen in the flexibility time series.

Nevertheless, may these arguments lead to a new strategy to determine a reasonable price for a bidding. From a forecast, a base price level could be taken and modified by an offset that depends on the flexibility forecasts. In this way low flexibility would lead to higher prices with the argument that the risk is higher but at the same time the probability of activations with higher prices is increased.

For now, we kept the models predicting price differences because they show the most stable behavior. Although they are not useable for short term price forecasts, they still show a decent estimate of value fluctuations in form of uncertainty estimations.

There are several directions for further work:

We should contact market experts and try to understand better what influencing factors are available for a better market model. This includes better understanding of the mechanisms of the normal operations market and expected effects of external events

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but also a better understanding of the players and their interests and actions in the market.

Also, instead of price or price change forecasts, the relationship between the price and the hydro reservoirs indicates that a model should be more successful, which predicts a price band for a time frame like e.g. a week. This information is still useful in composing offers for the normal operation market. It would give up the attempt to follow the market movement hourly but would explicitly model a price range. The current model estimates this as forecast uncertainty but it could be an independent model result in a future modelling approach.

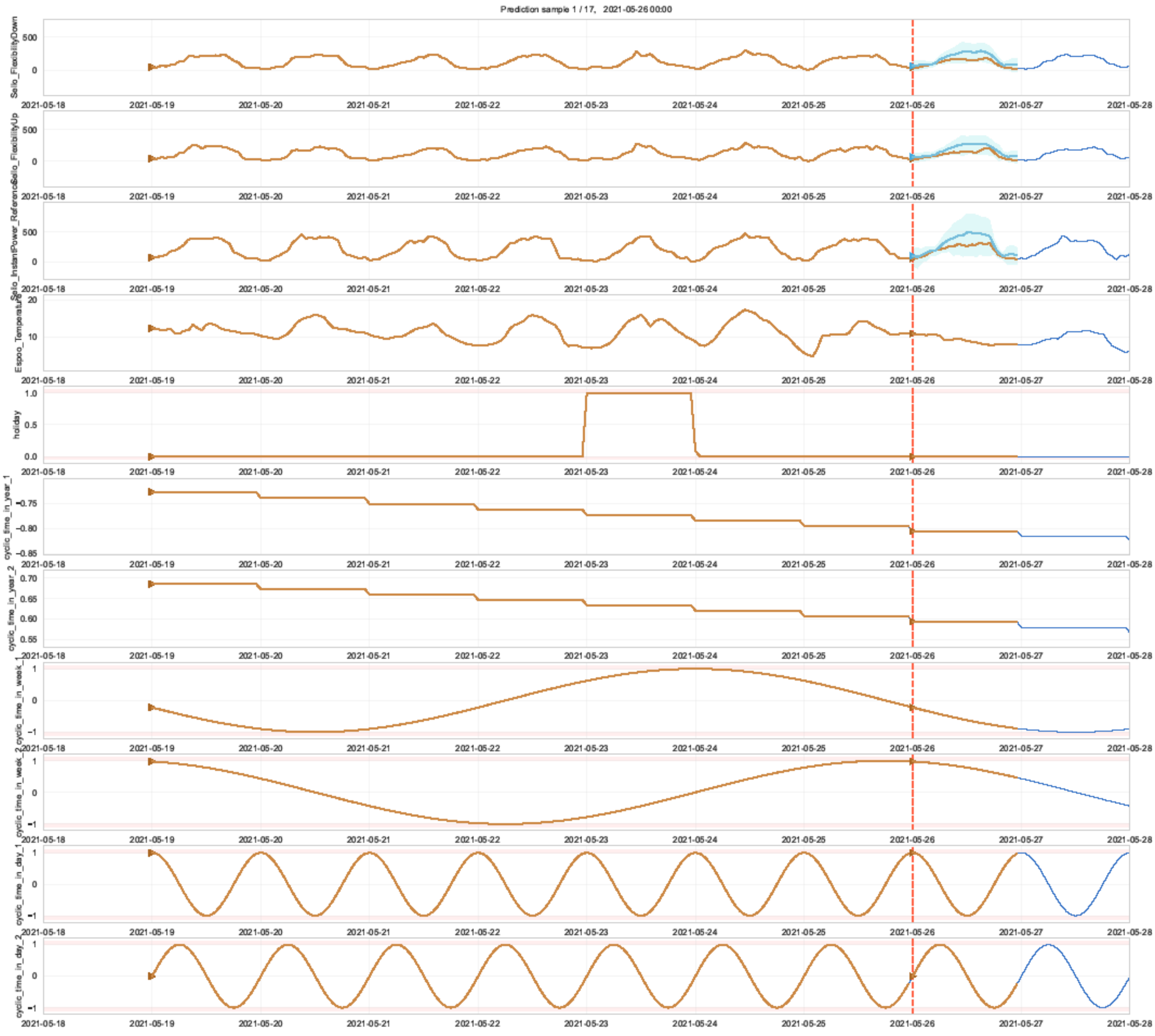

Figure 44. Sello Asset Flexibility Prediction. (Source: Siemens)

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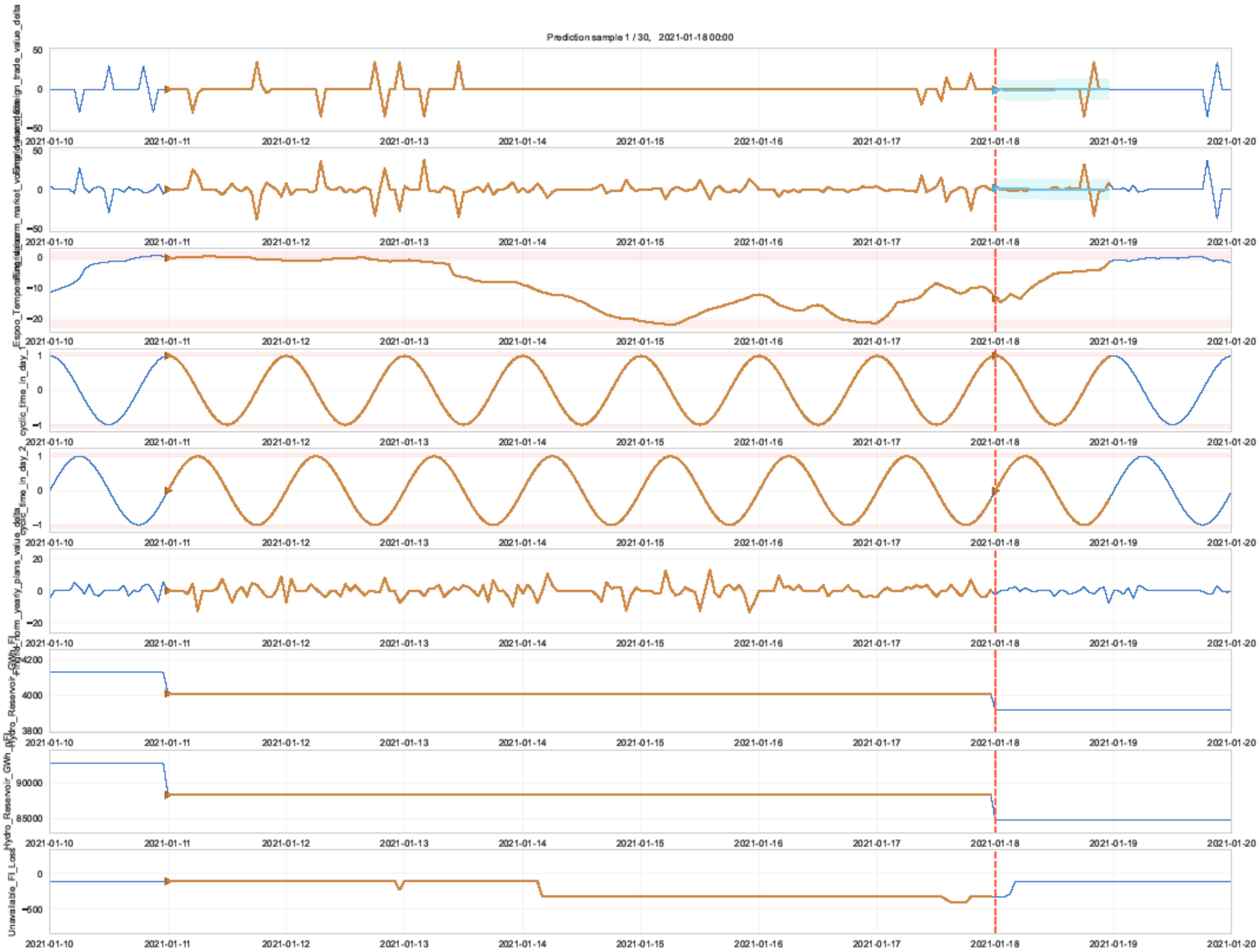

Figure 45. Fingrid FCR-N market prediction. (Source: Siemens)

An example of machine learning based online prediction models for Sello's next day electricity and heating energy demand are shown in Figure 46 below. The prediction model includes also Sello's next day predictions for electric cars charging power and PV based local electricity production. These prediction models has REST API's running in VTT's extranet server.

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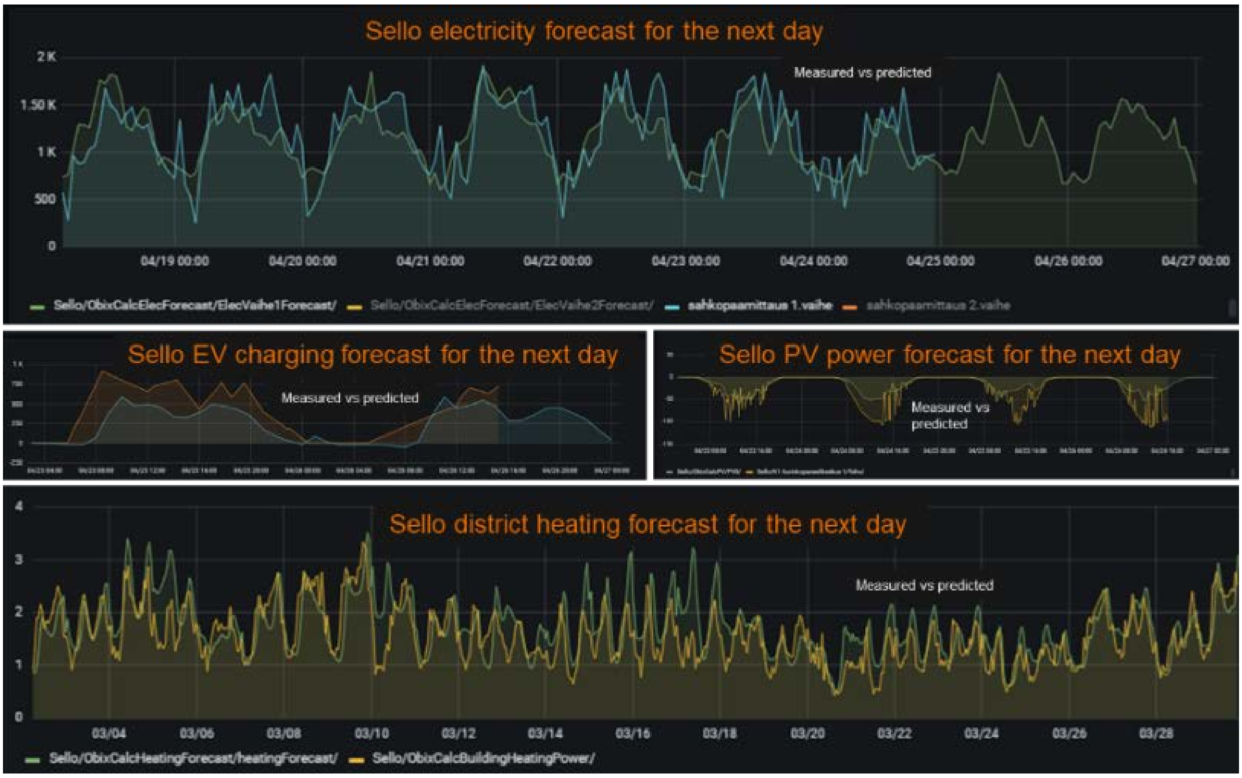

Figure 46. Example view of online energy prediction models for Sello developed in Action E6-1. (Source: VTT)

Action E15-1	**Feasibility study paving the background for the Virtual Power Plant formed from the loads of the local buildings to balance RES boosted local power network, identifying new business opportunities for aggregators in order to combine small demand response loads and offering them to reserve market (Fingrid). The target is to find and connect enough flexible loads from a local building stock (swimming pools, ice skating halls, sport halls, and office buildings) for 1 MW demand response, to participate in the electricity reserve markets.**
Detailed plan	• Gather data on all the Espoo city properties • Analyze reserve flexibility potential of different properties • Connect chosen loads and properties to VPP • Aggerate loads and offer them to reserve markets • Analyze results Similar activity on heat DSM in Action E16-1.
Targeted outcome	Enables city's properties to become active in energy sector by providing flexibility to reserve markets, to play a vital role in energy transformation. Understand flexibility potential of different type of properties.
Roles and responsibilities	SIE: Analyze flexibility potential, connect buildings to VPP and trade flexibility in reserve markets. ESP: Provide data on all Espoo city buildings. Enable work in the properties and in the systems required by VPP. VTT: Assess emission savings by VPP solution

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Main achievements till M36	Action E15-1 delivered: • Input data gathered • Analysis carried out • Short-list of most promising buildings for further analysis and site visits • Site visits conducted and feasible buildings identified • Pilot proposal made and feedback from the city received on this proposal • Based on the feedback, a decision to change the pilot target was made • Installation EV chargers in new pilot site • First loads traded in reserve markets • Analyze carried out • Loads traded in reserve markets • VTT collecting data for the assessment of emissions. ESP, SIE: Iteration of the solution in the first pilot site

Input data of feasible Espoo city properties was gathered and sent to Siemens for further analysis within action E15-1. The properties analyzed for this action had to meet a minimum annual electricity consumption of 150 MWh. In total, 98 public properties were identified for further analysis. These properties had a total electricity consumption of 51 000 MWh between 6/2019–6/2020, and an average consumption of 516 MWh in the same timeframe. The buildings identified in the preliminary analysis divided by type can be seen in the table below. It must be noted that in some cases buildings had been divided into several different entities in the City's building management software, and thus the number of total buildings below is different from the number provided above. For example, some school properties were divided into building A and building B, which were combined in later analysis.

Table 7. Buildings identified in preliminary VPP analysis by type.

Type	Amount
Healthcare	14
Day care centers	13
School buildings	53
Theaters and concert buildings	3
Shelters	2
Assembly buildings	3
Storage buildings	3
Depots	3
Transport buildings (e.g. parking garages)	2
Emergency services and fire departments	5
Offices and administrative buildings	2
Swimming halls	2
Other buildings	1
Food service	1
Total	**107**

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Within the table below, the buildings identified in the preliminary analysis are divided by the type of heating equipment. The fuel source used was not analyzed, but it can be assumed that most of the buildings under the type "Hot-water heating" utilize the local district heating grid.

Table 8. Buildings identified in preliminary VPP analysis by type of heating equipment.

Heating type	Amount
Hot-water heating	89
Electric heating	11
Air heating	2
No fixed heating equipment	3
No value	2
Total	**107**

Finally, the table below shows some interesting data points on the buildings under study. Approximately 40% of the identified buildings utilized smart heating solutions via Demand Side Management (DSM) provided by the local grid operator. The mean construction year was 1985, while 66% of the buildings have gone under further renovations. The mean renovation year was 2011. The City of Espoo has actively done condition assessments of its building stock to find further renovation needs and options to increase energy efficiency. From this data collection, 52% have been assessed between 2013 and 2020, with a mean assessment year of 2019. It must be noted that some buildings might have been assessed in either 2021 or 2022, as data might not be up to date.

Table 9. Data on buildings identified in the preliminary VPP analysis.

Type of data	Value
Buildings with heating DSM	42
Construction year (mean)	1985
Construction year (minimum)	1890
Construction year (maximum)	2019
Buildings that have been renovated	71
Renovation year (mean)	2011
Buildings with completed condition assessment	56
Assessment year (mean)	2019

From this preliminary analysis, a total of 13 buildings were chosen for site visits and a further round of assessments. These buildings divided by type can be seen in the table below. Three buildings with the best potential for VPP connectivity were identified.

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Potential identified solutions were the control of peak loads, frequency regulation, electricity storage, EV charging and optimization of electricity consumption.

Table 10. Buildings chosen for site visits by type.

Type	Amount
School buildings	10
Swimming hall	1
Ice hall	1
Shelter	1

Matinkylä ice sport center, called Ilmatar Arena, was chosen as a pilot project. Ilmatar Arena is named after renewable energy company and supplies wind energy to the arena. Arena is a new energy efficient building complex, which besides of three indoor ice rinks, includes indoor exercise halls and gyms, café-restaurant and multiple meeting and office rooms. Additionally, there is an outdoor ice ring during the winter and football field during the other seasons, supported with locker rooms in the arena. For example, the exhaust heat caused by cooling the ice is used for space heating of warmer areas. Approximately 80–90% of the heat demand is covered with the exhaust heat.

Figure 47. Ilmatar Arena main entrance and one of the three ice rinks.

The objective of the actions was to demonstrate a concept for Espoo city, on integration of loads into peak power limitation to allow installation of electric vehicle (EV) charging units without a possible electricity grid connection upgrade. Aim was also to demonstrate integration of EV loads and manage electrical loads of an ice hall for purposes of peak shaving and to provide services to the grid that involve adjusting the amount of power the vehicle pulls while charging, in response to signals from the grid.

The solution will be piloted with EV chargers installed for the SPARCS task at the Matinkylä indoor ice sport center. The EV chargers include 8 AC chargers with maximum electric power output of 22 kW/charger and one DC charger with maximum output power of 160 kW.

The solution is to connect the electricity grid connection metering, the EV chargers and the building automation assets to Siemens Power Manager, which can control and optimize the usage of the connection. The Power Manager monitors the power taken

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from the grid connection. When the pre-set limits for power are reached, Power Manager sends commands to the EV chargers to lower their output power. The EV chargers have an internal control logic, how the power limitation is distributed among the fleet of chargers. The EV charger logic is provided by the operator Plugit. All the connections between individual systems use standard protocols and interfaces. More detailed topology can be found in the Picture 1 below.

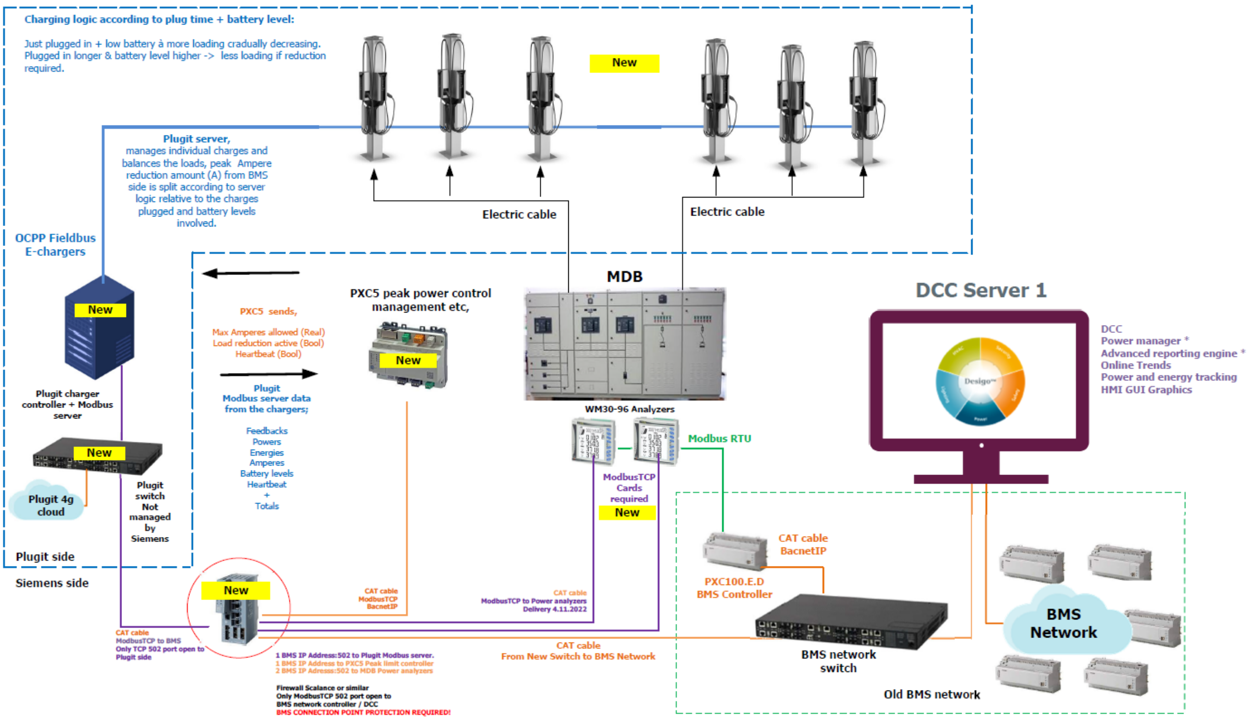

Figure 48. Topology of Matinkylä ice sport center power limitation with EV chargers. (Siemens 2022)

Since the ice sport center is a new building, and it has opened in November 2021, during the project planning and design there were already reservations made for EV chargers and other power needs in the future. Consequently, the physical limits of power connection are not really a problem. Rather, the goal is to make sure the system functions properly and the limits can be adjusted based on the needs. Therefore, the solution has the potential to be scalable and may be copied and applied in almost any other building with EV chargers and building automation without expensive grid connection upgrades. Only limitation are the connection and control protocols.

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Figure 49. Installed EV chargers in Ilmatar arena, 8x22kW AC chargers and 1x160 kW DC charger. (Source: Siemens)

The installation of systems was finished in September 2022 and the overall system will be optimized and adjusted based on the collected data during the next two years during the SPARCS monitoring phase.

Action E15-2	**Blockchain technology options for supporting demand response and Virtual Power Plant in positive energy districts. Blockchain enabled business cases and control strategies will be studied, while possible policy and regulation related challenges will be identified.**
Detailed plan	1. Assessment of pros and cons of blockchain solutions. 2. Identification of most promising applications for blockchain. 3. Assessment of legal framework. Ref Action E12-3 Blockchains for Kera energy transactions.
Targeted outcome	Blockchains may prove a cost-efficient and reliable platform for energy prosumer and demand side management transactions
Roles and responsibilities	ESP: Overall coordination VTT: Technical support on blockchain solutions

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	SIE: Commercialized blockchain services
Main achievements till M36	Action E15-2 delivered: • The architecture of blockchain solutions was identified • Pros and cons of blockchain solutions for the energy sector were assessed • The most promising opportunities and applications for blockchain were identified, together with their connection to the city strategy. • The role of the City of Espoo in possible blockchain applications or pilots was identified • The legal framework around blockchain was assessed. • Findings were documented, and a roadmap for the future was devised.

Blockchain Solutions for the Energy Sector: SPARCS Feasibility Study

Since 2008 and the invention of Bitcoin, blockchains have been one of the most rapidly growing ICT technologies with possible applications in several different fields, such as finance, logistics and energy. Blockchain, or Distributed Ledger Technology (DLT), is a technology that can be used to store information securely in a decentralized manner without the aid of trusted third parties. This is due to the information being simultaneously stored on many resources known as nodes, which can be computers, servers or other devices which connect to the network and store and transfer information. Thus, trust and verification is enabled via collectivized supervision and storage. Distributed storage ensures that the data remains unaltered even if a single compromised node of the network alters any information within the blockchain, and distributed supervision ensures that all decisions made between the participants are decided upon securely even when trust is not present. In the energy sector, blockchains could be an especially useful technology in providing solutions for tracking, transferring, and collecting data in decentralized applications.

With a unique opportunity of working with partners that have an interest in the business of blockchain technologies within the energy sector, SPARCS provides an opportunity for investigating blockchain as a solution for the energy field both locally and internationally. To achieve this, a feasibility study was developed to substantiate any benefits that blockchains offer compared to business as usual within the selected themes of VPP's and Demand Response (DR) within action E15-2, and bi-directional energy transfer within action E12-3. Pros and cons of different blockchain solutions were analyzed in relation to how they can be used within these fields. In addition, use cases of blockchain solutions were presented and the current legal and regulatory framework was analyzed. (Mäkinen, 2022)

Action E17-1	**Virtual twin of a real demo for a positive energy building block, to build a showcase and support replication. Provides both the visual of the building and the operational behavior (same energy load as in the real buildings and the block) for the building energy system.**
Detailed plan	Building of a virtual twin for Sello. The v~~V~~irtual twin focuses on predicting electricity demand and on-site electricity production from PV. It can also help to run the Virtual Power Plant (VPP) in Sello. It is o~~O~~ptional (if suitable data received from Sello) to include the electricity battery, EV charging and

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	participation to the electricity market (FCR-N). The ~~V~~virtual twin visualizes also the measurement values and the results in a building model. The v~~V~~irtual twin also will have heat energy included, in connection to action E5-1: heat performance and storing energy to building structures.
Targeted outcome	The v~~V~~irtual twin predicts online the electricity and heating demand, as well as PV production and electric car charging power in Sello for the next 24 hours (with as small difference to monitored data as possible). This can be used also for optimisation purposes. The monitored data and results of virtual twin can be visualised in a 3D BIM based building model.
Roles and responsibilities	VTT: Virtual twin planning and building. Stakeholders: Giving data and BIM model from Sello.
Main achievements till M36	Action E17-1 delivered: • First version of the v~~V~~irtual twin for predicting electricity demand during 2020 (by M15). • Final version of the online connected virtual twin of Sello is ready including next new features • Online predicting PV production added in spring 2021. • Online predicting electric car charging power added in summer 2021. • Online predicting district heating demand added in spring 2022. • 3D BIM based online monitoring and visual analytics of building near real-time and history energy and HVAC data added in summer 2022.

The Sello virtual twin concept is shown in Figure 50.

The basic idea of the Sello virtual twin is that it looks the same as real Sello and it behaves like the real Sello, but it is not the real Sello. It is only a digital copy of Sello from energy point of view.

The main features of the Sello virtual twin includes

- Predicting next day energy consumption & production (see E6-1, Figure 46) 3D BIM based monitoring and visual analysing energy & HVAC data (see Figure 51 below)

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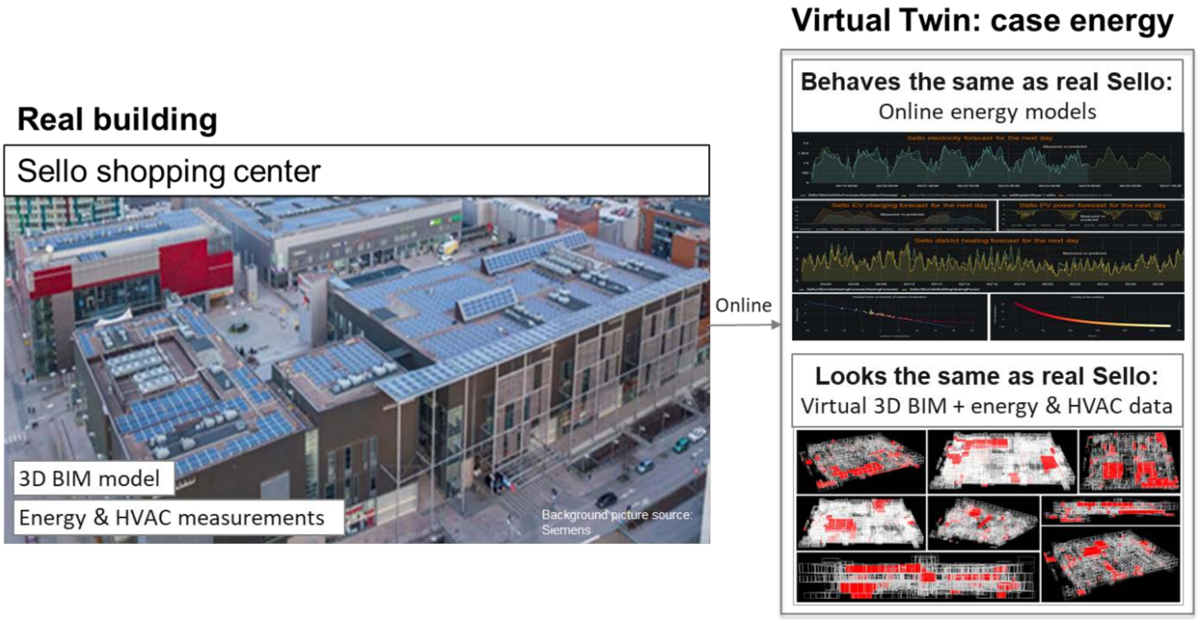

Figure 50. Sello virtual twin concept. (Source: VTT)

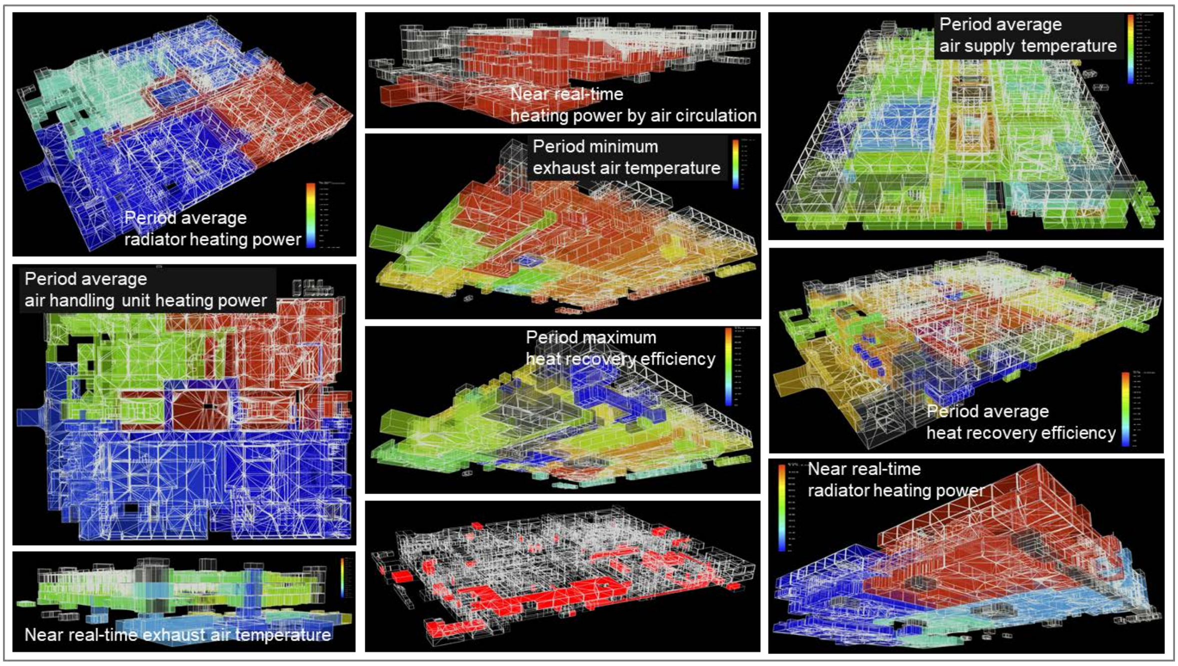

Figure 51. Examples of Virtual Twin feature "3D BIM based monitoring and visual analysing energy & HVAC data". (Source: VTT)

The virtual twin makes it possible to visualize selected energy or HVAC near real-time or historic data by 3D BIM based virtual model. This second main feature for the Sello virtual twin feature is a web browser based on-line data connected application (developed by VTT), which reads Sello's spaces from BIM model (IFC file or BIM model server) and maps Sello's historical or near real time measured data to Sello's 3D BIM model elements. More detailed, the data can be measured (e.g. heating energy consumption, exhaust air temperature) or calculated (e.g. heat recovery efficiency). From a visualisation point of view, it is possible to show e.g. average, minimum or

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maximum values in different part of the building (e.g. in HVAC system zones or spaces). In the Sello virtual twin next data are mapped to 3D BIM model:

- Radiator heating power in different heating zones
- Air handling unit heating power in different air handling units' effect zones
- Air circulation related heating power in different air handling units' effect zones
- Supply air temperature in different air handling units' effect zones
- Exhaust air temperature in different air handling units' effect zones
- Heat recovery efficiency in different air handling units' effect zones

This 3D BIM based visualization makes it possible to check e.g. in which part of the building selected variable (e.g. heating energy consumption) was too high or too low in the selected time (now, last spring, etc.). It is also possible to utilize the virtual twin when optimizing local energy use or detecting and locating energy related faults from studied building.

4.3 Smart energy services

Modern energy services can be provided more efficiently, flexibly and reliably if they are based on an appropriate ICT platform. 5G technology is an established global standard for mobile connectivity, and it enables the control of a high number of appliances. Blockchain and IoT are evolving quickly, presenting new opportunities for optimised energy performance and innovative new business models. The detailed plans are presented in the following tables.

Two actions within this subtask focus on identifying opportunities offered by the Kera local district 5G network piloted within the LuxTurrim5G, Luxturrim5G+ and Neutral Host Pilot projects. The results of these projects were utilized to identify synergies between 5G, smart energy infrastructure and e-mobility. An additional aim was to identify possible service models to be used within Kera or in additional regions where this local 5G network could be expanded to. In addition, opportunities brought to Kera by blockchain technologies were investigated in Action E12-3.

Action E6-2	Feasibility study on of smart energy services for residential and office buildings, based on digital platform, including EV charging, centralized battery energy storage and VPP. Evaluation of Electric Peak load management for residential and office buildings including EV charging stations.
Detailed plan	• Assess feasible scope of buildings in Leppävaara district to be included. • Estimate power demand profiles. • Chose buildings for feasibility study
Targeted outcome	Feasibility study on of smart energy services for residential buildings, based on digital platform, including EV charging, centralized battery energy storage and smart energy platform.
Roles and responsibilities	SIE: Assess the flexibility potential, create a technical solution, assess business model ESP: Engage stakeholders including public buildings and Espoon Asunnot in Leppävaara district

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Main achievements till M36	Action E6-2 delivered: • Mapping the scope of buildings • Relevant data of buildings provided to Siemens • A feasibility study carried out Value of digital platform and VPP is demonstrated in Action E6-1

Primary objective of this feasibility study is the design of the battery system for a residential building in Espoo Finland.

In this report the following will be examined:

- Evaluate if battery solution makes business sense and estimate battery capacity.
- Payback time of EV charger installation with solar panels rather than updating grid connection.

4.3.1 Energy Dispatch Simulations

4.3.1.1 Simulation software

The simulation tool used in this project is called PSS®DE, which is used for optimizing and evaluation of distributed energy systems. PSS®DE considers user defined configurations and simulates the system based on input data such as load profiles, grid tariffs, estimated weather condition, battery storage, solar power etc.

Figure below shows the model with input as represented in PSS®DE with its components.

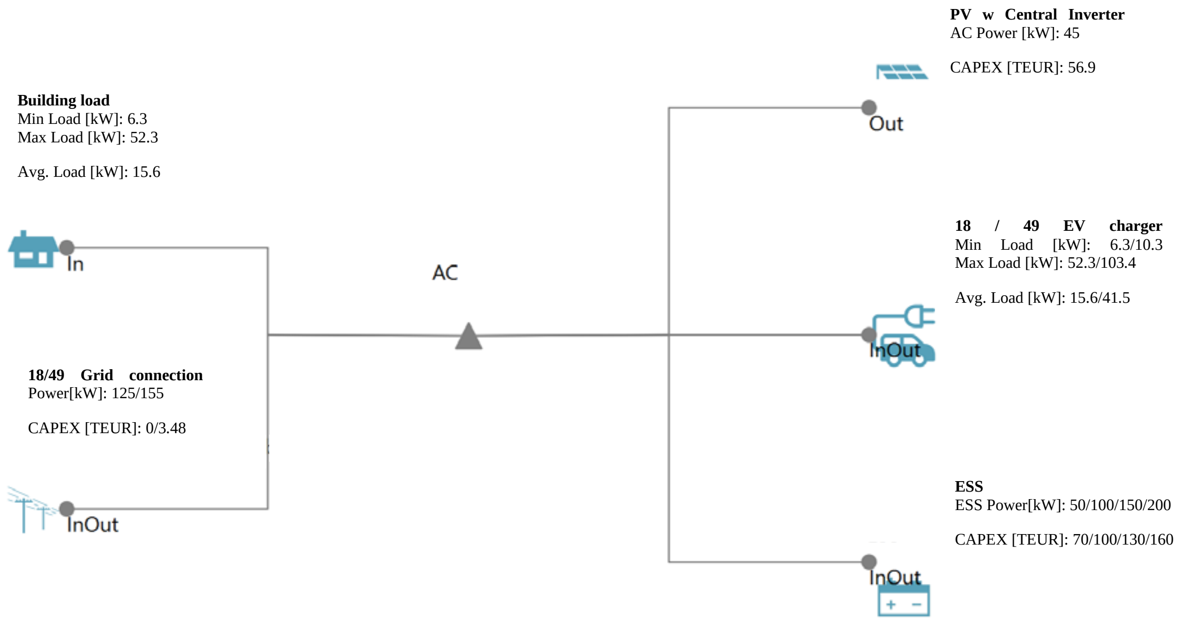

Figure 52. Simulation model in PSS®DE. (Source: Siemens)

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4.3.1.2 Residential loads and Electrical Vehicles (EV)

Load profiles of the residential loads are received from customer. The data is measured kWh from period 01.01.2021–30.04.2022. Only data from 2021 are used in the software and the loads are inserted as kW, hence kW are assumed to be equal to kWh. The loads are not expected to increase.

A typical week is shown in Figure 53.

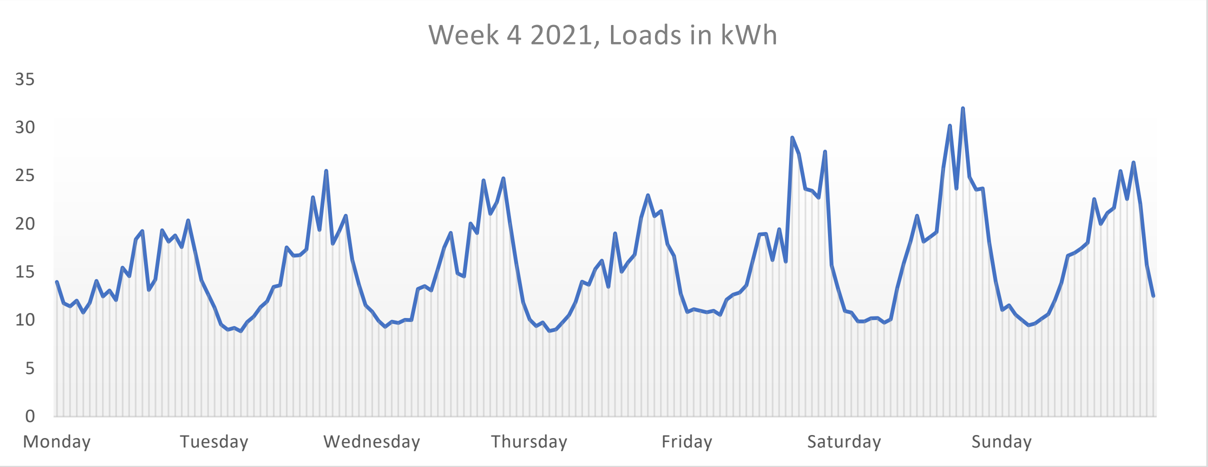

Figure 53. Load profile of the residential loads: A typical week. (Source: Siemens)

Load profiles on EV charging was not provided in this project. The profiles are hence based on [1], and the simultaneity factor is assumed to 10%, based on weekend charging in [2].

Two configurations for number of charges are simulated:

- 18 charging points
- 49 charging points

All chargers are modelled with an installed capacity of 11 kW.

A typical week for both configurations is shown in Figure 54.

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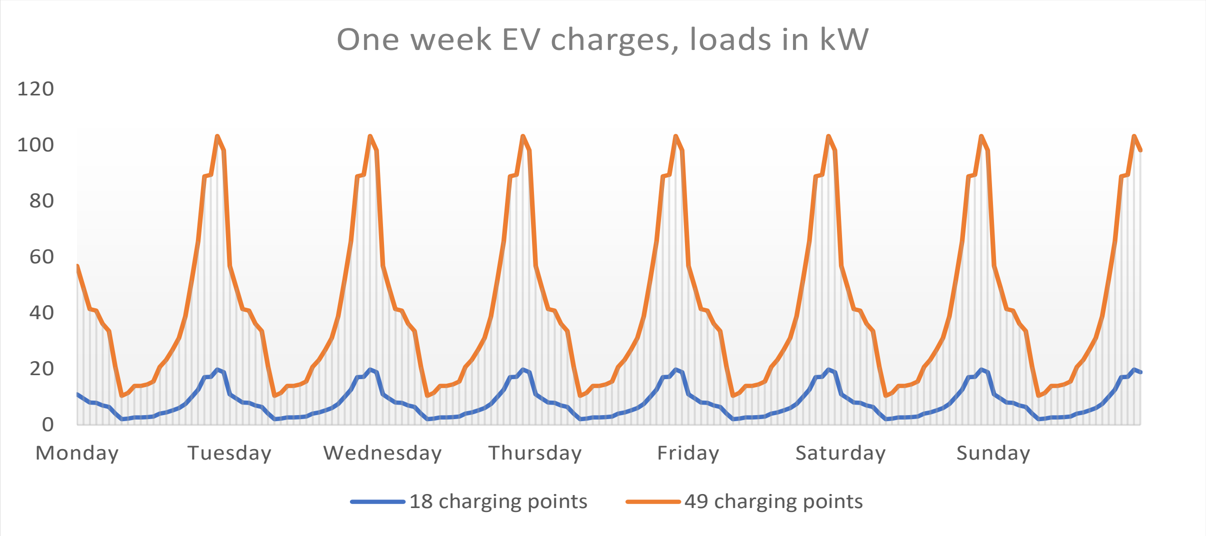

Figure 54. Load profile for EV charging: A typical week (Source: Siemens)

4.3.1.3 Batteries

Batteries with power rating from 50–200 kW have been simulated. Table 11 shows input data on different batteries.

Table 11. Batteries.

Power [kW]	Capacity[kWh]	C-factor	CAPEX
50	46.5	1.22	70 TEUR
100	92.9	1.22	100 TEUR
150	123.9	1.22	130 TEUR
200	185.9	1.22	160 TEUR

4.3.1.4 Photovoltaic

The roof on the building has an area of 660 m^2. Based on similar projects Siemens have been involved in, it is assumed installed capacity of 45 kWp.

No solar measurements have been carried out for the area and the data has been obtained from Meteonorm, which has a unique combination of reliable data sources and sophisticated calculation tools. They provide access to typical years and historical time series. Data has been obtained on ambient temperature, direct and diffuse solar radiation. The data range from 0.0 to 963 W/m^2 with an overall average of 126.7 W/m^2 for direct solar radiation. For diffuse radiation, the data ranges from 0.00 to 383 W/m^2 with an average of 52.4 W/m^2.

The energy production simulated is shown in Figure 55. The peak and average production is respectively 39.15 kW and 4.95 kW.

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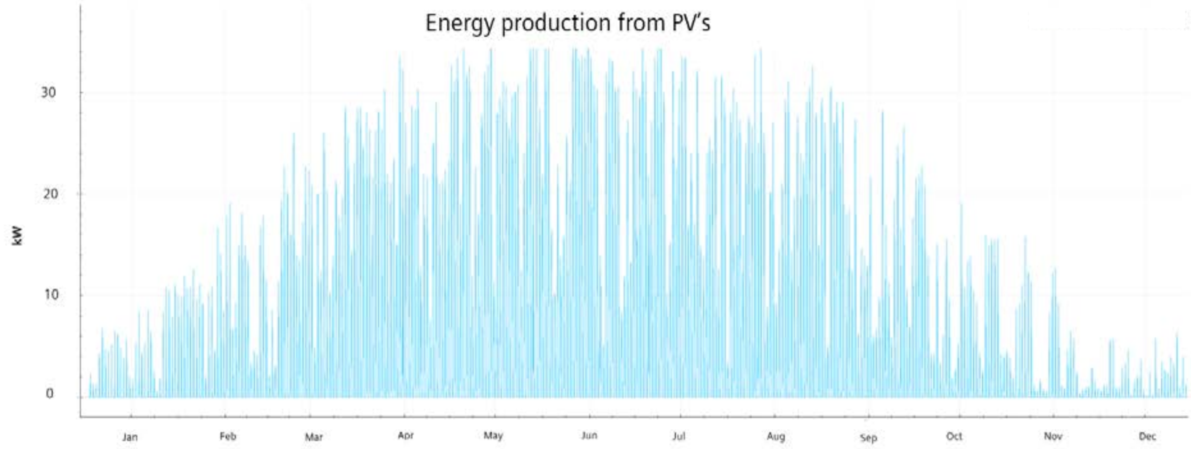

Figure 55. Energy production from solar power during a year. (Source: Siemens)

4.3.1.5 Grid connection and tariffs

Grid connection:

The grid connection is limited to the 3 x 200 A fuses on incoming cables. This corresponds to disconnection when the loads exceeds ~ 140 kVA. <u>125 kW is assumed as maximum loading</u> in this project which corresponds to a power factor (cos φ) of 0,9.

Initial simulations show that the load profiles assumed in chapter 4.3.1.2 exceeds the 125 kW by 30 kW at peak (i.e. maximum 155 kW) for the 49 EV charging point configuration. Accordingly with prices for grid upgrade an increase in 50 A (~ 33 kVA, 33 kW) the CAPEX is 3 480 €. This will be added when running the 49 EV charging point configuration.

Grid tariff:

There are three different network products available in the Espoo area *general distribution (tariff 1)*, *night-time distribution* (tariff 2) and *seasonal distribution* (tariff 3) in which all includes basic fee (€/month) and addition to cost of electricity (c/kWh) and taxes.

Initially the three net tariffs were simulated with and without a 100 kW battery. Figure 56 present the cost related to imported electricity from the grid for each of these six scenarios.

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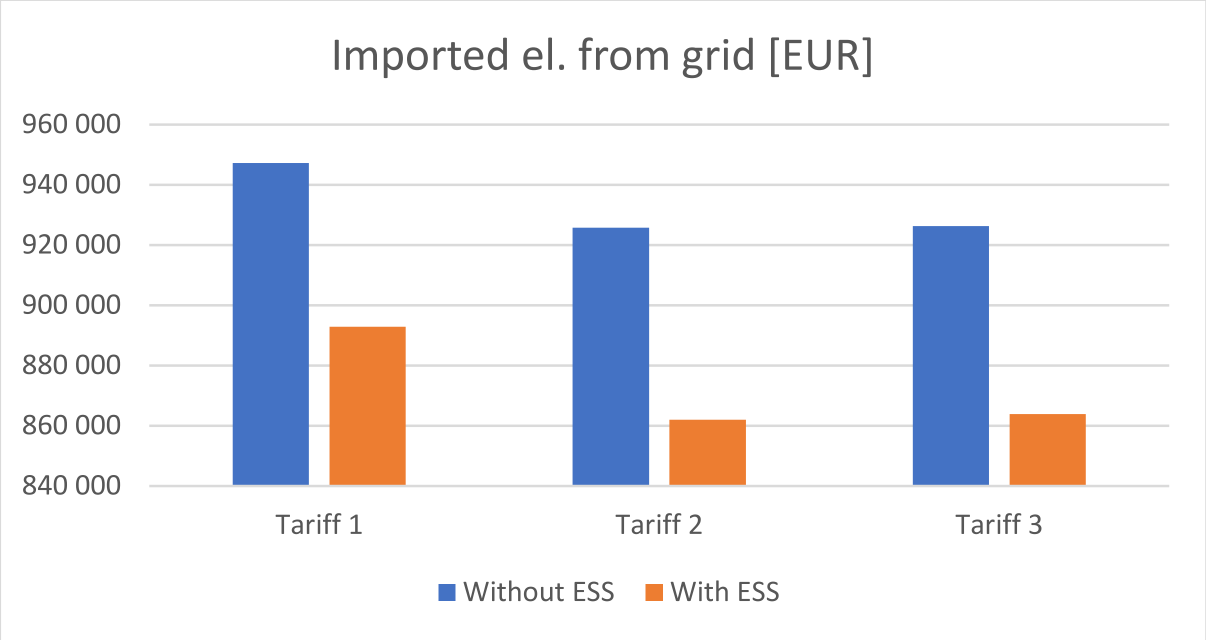

Figure 56. Comparison of grid tariffs. (Source: Siemens)

The cost of electricity from the grid for Tariff 1 is notably higher than for the two remaining tariffs. Tariff 2 and Tariff 3 present similar results, and it is hence decided to continue the report with Tariff 2.

4.3.1.6 Scenarios and assumptions

Scenarios:

The first scenario is performed in order to determine the optimal battery size (kW). The simulations include different configurations of the system to identify the feasibility of batteries and their size. Ten configurations are run in total, as shown Figure 57.

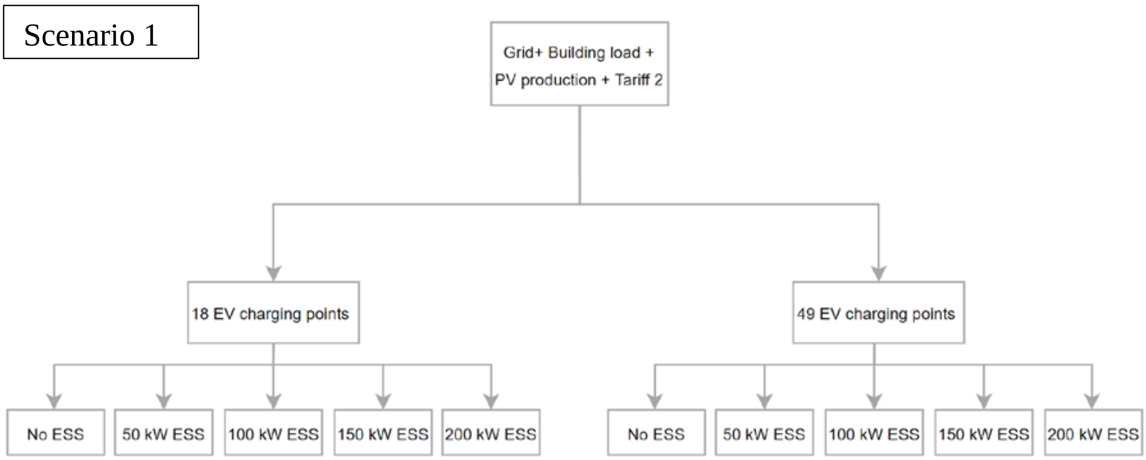

Figure 57. ESS configurations simulated for scenario 1 (Source: Siemens)

After the optimum battery size is decided, a simulation without PV is conduced to consider the benefits of PVs. In addition, scenarios without the 200 kW battery are

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simulated, as seen in Figure 58. The PV power production fluctuates throughout the year as presented in Figure 55. PVs can hence not provide the surplus power required for large parts of the year. As an example, there is low power production throughout November in the simulation, leading to less power production contribution and hence higher payback time for the PVs. The payback time of PVs will be presented independent of grid upgrade.

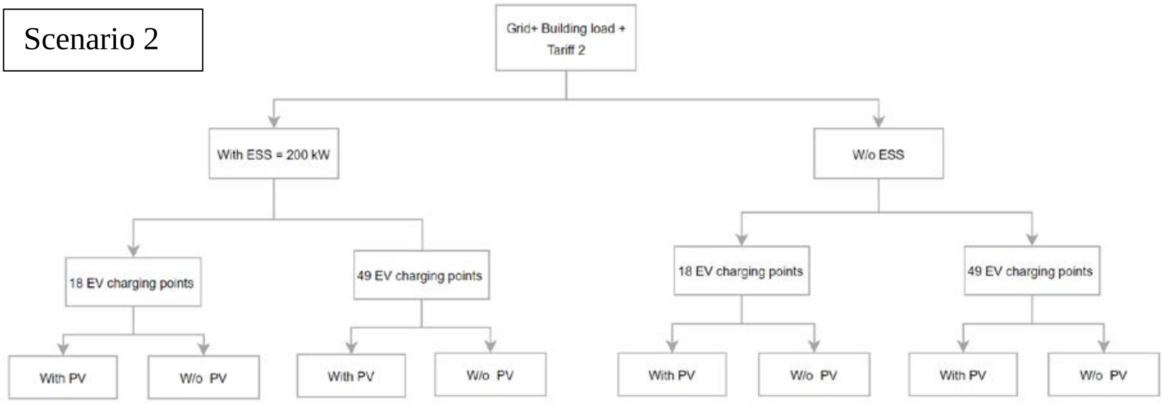

Figure 58. PV configurations for scenario 2. (Source: Siemens)

Scenario 3 will look at the combination of PV + ESS in comparison to the grid supply. The configurations are performed for both the 18 and 49 CP load with the optimal battery size. The four configurations are presented in Figure 59.

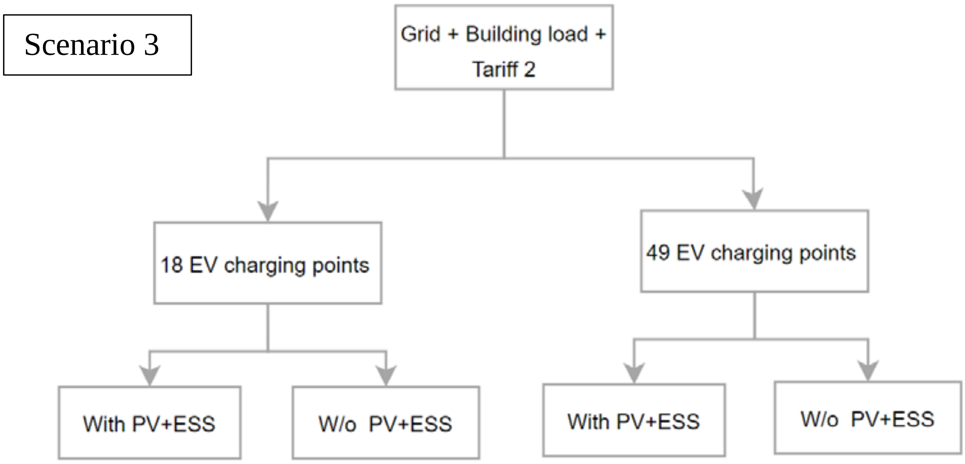

Figure 59. PV and ESS configurations for scenario 3. (Source: Siemens)

Assumptions:

- Electricity prices is based on the monthly average day-ahead prices for Finland [3]. To obtain hourly prices, electricity prices from another Siemens project is used: electricity prices in Stavanger, Norway 2018. The data is then scaled to have the same monthly average as Finland in 2021.
- A 50% increase in electricity prices is assumed over the next ten-year period. This is the increase in Finland energy prices from January 2008 to august 2021. Data from the end of 2021 and the whole of 2022 is excluded, as this time period

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has had some irregular high electricity prices. If these prices were to be included, the profitability of the scenarios would be notably higher, resulting in artificially low payback time.

- The simulation period is set to 20 years.
- PV are modelled as ideal. In practice there will be OPEX for service and maintenance.
- Solar data for the location is obtained from Meteonorm (Meteotest AG, u.d.), as described in chapter 4.3.1.4.

4.3.2 Simulation results

4.3.2.1 Scenario 1: Battery size optimization

4.3.2.1.1 18 EV Charging points

Table 12 presents the total cost and payback time for the 18 charging points with no ESS, 50 kW, 100 kW, 150 kW and 200 kW respectively. 200 kW is the best option with a payback time of almost 20 years.

Table 12. Results for configuration with 18 CP.

CP = 18	ESS [kW]				
	w/o ESS	50	100	150	200
Total cost[EUR] [3]	1 469 586	1 560 180	1 536 002	1 525 348	1 469 128
Payback time[y] [4]	-	20+	20+	20+	19.9

Figure 60 shows the sankey diagram of simulation results with 200 kW batteries.

[3] Total cost represents all costs during the project lifetime (including CAPEX, OPEX, CoE)

[4] Payback time is calculated by comparing the CoE (with and w/o ESS) against CAPEX. $-(CAPEX_{w\ ESS} - CAPEX_{w/o\ ESS}) + (CoE_{w/o\ ESS} - CoE_{w\ ESS})$

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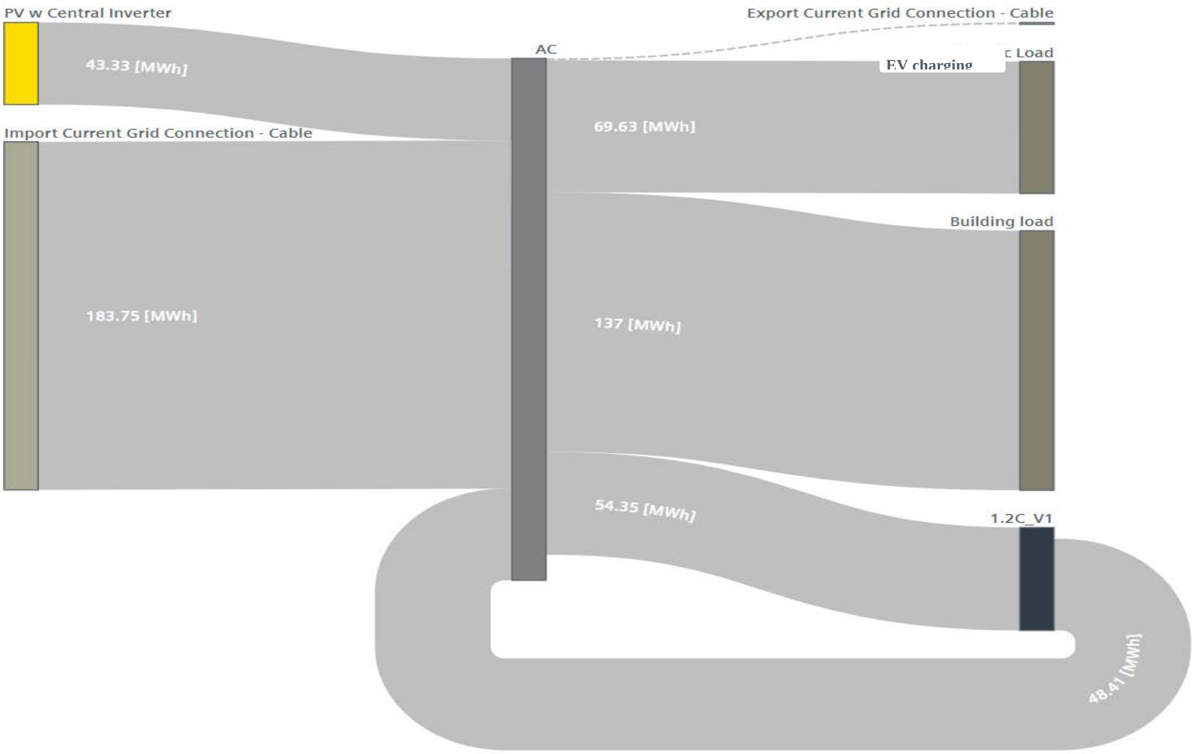

Figure 60. Simulations results for 200 kW battery (18 EV CPs). (Source: Siemens)

4.3.2.1.2 49 EV Charging points

Table 13 presents the total cost and payback time for the 49 charging points with no ESS, 50 kW, 100 kW, 150 kW and 200 kW respectively. 200 kW is the best option with a payback time of almost 19 years.

Table 13. Results for configuration with 49 CP.

CP = 49	ESS [kW]				
	w/o ESS	50	100	150	200
Total cost[EUR] [3]	3 662 365	3 771 832	3 737 468	3 715 954	3 633 578
Payback time[y]	-	20+	20+	20+	18.7

Figure 61 shows the sankey diagram of simulation results with 200 kW batteries.

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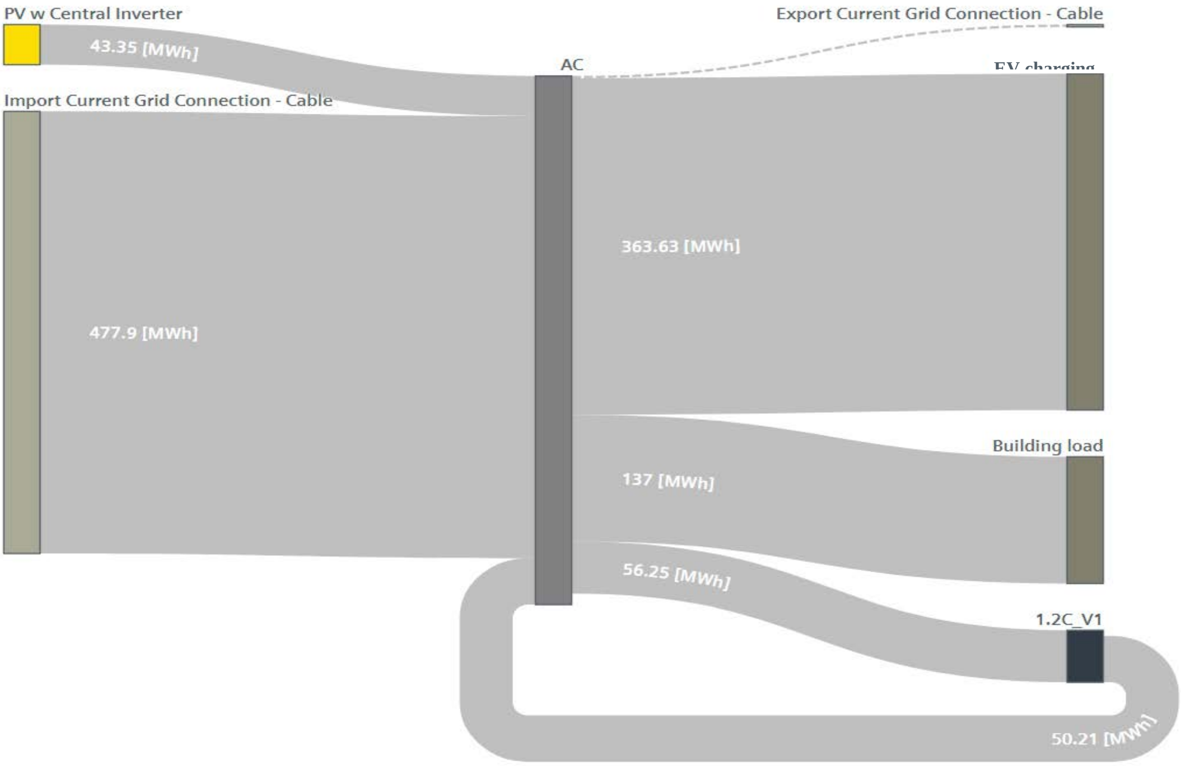

Figure 61. Simulations results for 200 kW battery (49 EV CPs). (Source: Siemens)

4.3.2.2 Scenario 2: With and without PV

Table 14 presents the total cost and payback time with and without PVs. The simulation is performed with a 200 kW battery, as this gave the best payback time for both EV cases.

Table 14. Results for configuration with and without PV.

CP = 18	w/o ESS		ESS = 200 [kW]	
	w/o PV	w PV	w/o PV	w PV
Total cost[EUR] [3]	1 810 092	1 469 685	1 777 286	1 465 663
Payback time[y]	-	4.6	-	4.3

CP = 49	w/o ESS		ESS = 200 [kW]	
	w/o PV	w PV	w/o PV	w PV
Total cost[EUR]	4 048 513	3 670 225	4 002 003	3 649 322
Payback time[y]	-	3	-	3.2

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4.3.2.3 Scenario 3: With and without PV + ESS

Table 15 presents the total cost and payback time for the grid, as well as for the configuration including PVs and a 200 kW battery. The configurations include either 18 or 49 CPs.

Table 15. Results from configurations with and without PV and ESS.

	CP = 18		CP = 49	
	w/o PV+ESS	w PV+ESS	w/o PV+ESS	w PV+ESS
Total cost[EUR] [3]	1 810 092	1 478 638	4 048 513	3 653 608
Payback time[y]	-	9.2	-	8.3

The configuration without PV and ESS has some missing power throughout the year, as seen in Figure 62. As the peak of missing power is around 22 kW, there will not be a need for a grid upgrade with any of the battery sized (50–200 kW) reviewed in this report.

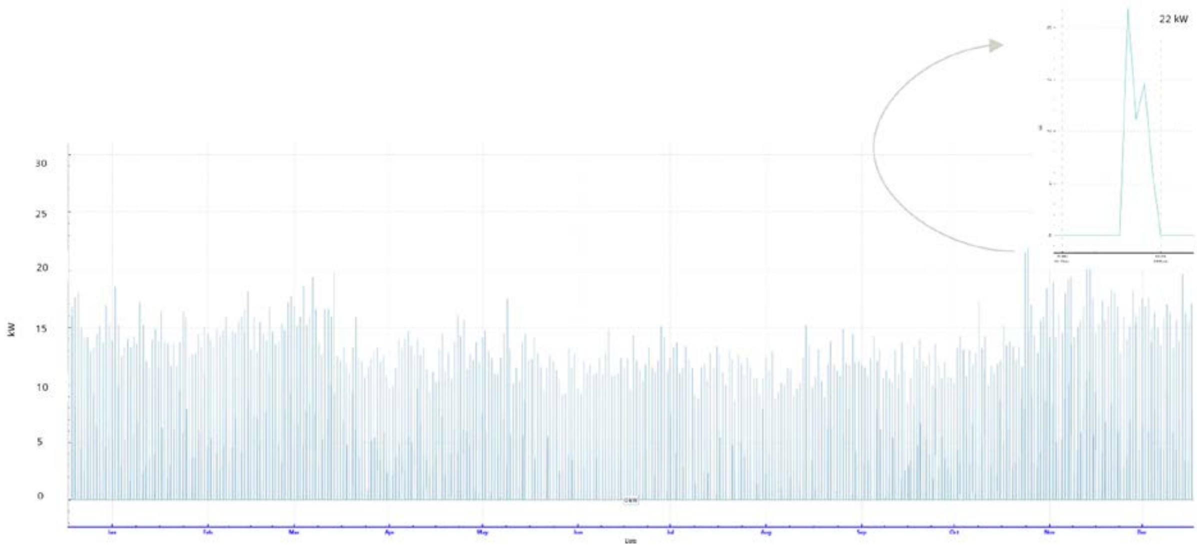

Figure 62. Missing power with 125 kW grid and 49 CP load. (Source: Siemens)

4.3.3 Recommendations

Evaluation of battery solution:

The recommended battery size is 200 kW for both 18 and 49 charging points according to the simulation results, as both total cost and hence the payback time is shorter for the 200 kW battery scenario than without batteries.

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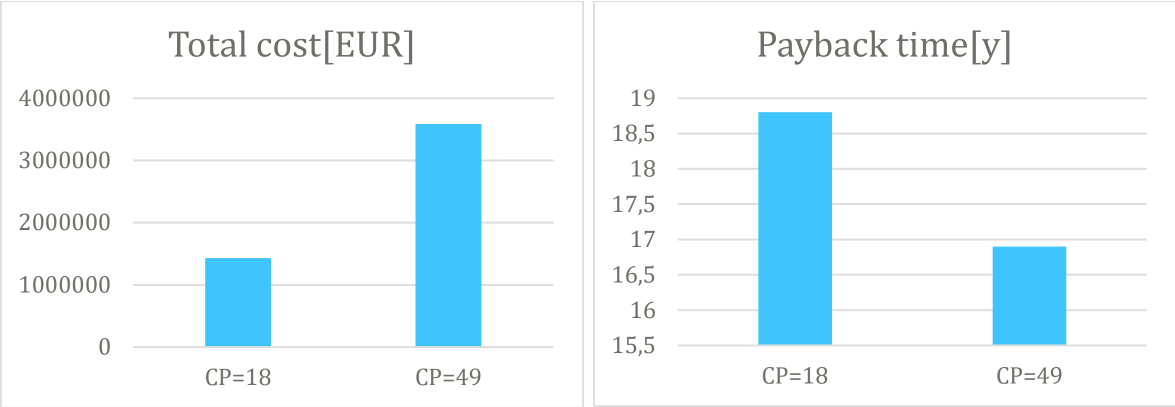

The simulation has been performed without battery losses and with assumed EV load profiles based on available literature. Batteries reduces CoE by charging at lower energy prices and discharging at high energy prices (c/kWh). Batteries would have been even more feasible with tariffs for power (c/kW) – more cost reduction from peak shaving.

Payback time of EV installation for PV and grid upgrade:

Initial simulations shows that EV installation cannot avoid grid upgrade. This is because the energy production is low large parts of the year. Therefore, a grid upgrade will be necessary for 49 CPs with the load profile simulated. However, PV is shown to have a relatively small payback time with the assumed CAPEX. Also, the PV are modelled as ideal and in practice there will be OPEX for service and maintenance.

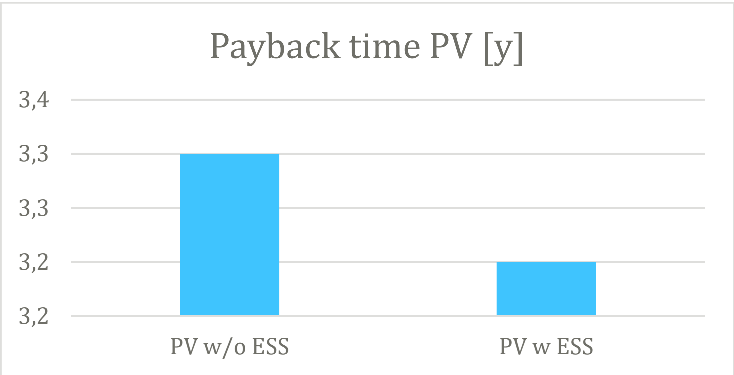

Figure 63. Payback time for with PV (with and without 200 kW ESS) PV and ESS configura. (Source: Siemens).

PV and 200 kW ESS together has payback time of 9,2 and 8,3 years for 18 and 49 CP, respectively.

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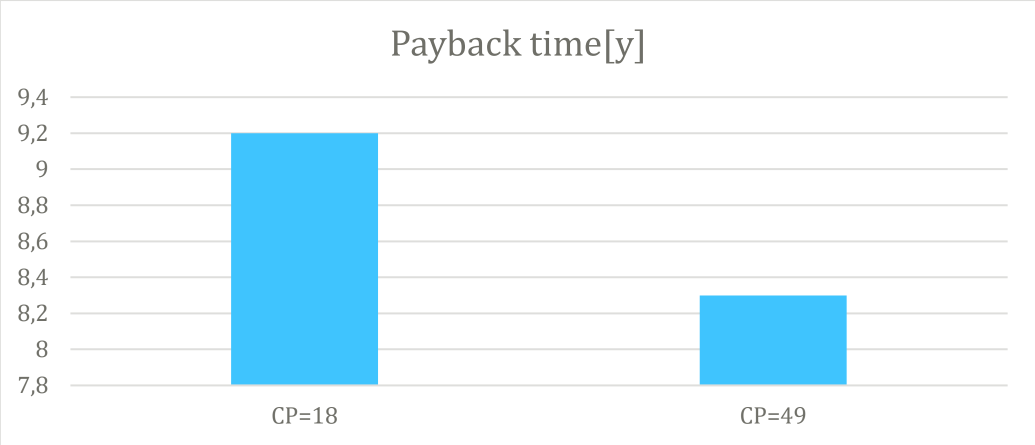

Figure 64. Payback time for grid connection, PV and 200 kW ESS solution with respectively 18 or 49 CP. (Source: Siemens)

With the EV loads profiles simulated, all batteries (50–200 kW) will remove the need for grid upgrades (>3x200A fuses), because the missing power is ~22kW at peak.

Action E12-1	**Smart infrastructure 5G. Investigating opportunities offered by the Kera digital platform and local district 5G network for management of the smart power grid, optimization, bi-directional energy flows, energy demand side management and demand flexibility.**
Detailed plan	• Investigate and document current 5G projects in Kera and elsewhere. • Conduct literature review on 5G and smart infrastructure • Identify opportunities for synergies in energy efficiency, DSM, prosumer. transactions and innovative business models. • Map and document key stakeholders. • Document findings, report and communicate.
Targeted outcome	Energy performance optimization requires automation and smart solutions to ensure energy savings, cost effectiveness and reliable operation. 5G infrastructure facilitates smart energy.
Roles and responsibilities	ESP: Main responsibility. Stakeholders
Main achievements till M36	Action E12-1 delivered: • Current projects documented, and literature review conducted • Opportunities identified, stakeholders mapped and documented • Opportunities for synergies in energy efficiency, DSM, prosumer transactions and innovative business models identified • Findings documented, reported and communicated. The development of smart solutions within the energy infrastructure, together with new developments in the utilization of 5G within these solutions, will be constantly monitored and the literature review will be updated if needed.

Within actions E12-1 and E12-2, the SPARCS project aimed to assess the relevance of 5G within the energy and mobility sectors. Within the energy sector, a focus on the

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smart grid, optimization solutions, bi-directional energy flows and demand side management was chosen, while the mobility section focused on autonomous mobility and Vehicle-to-Grid (V2G). To achieve this, a literature study of these themes was conducted. In this section, excerpts of this study are shown. The full study will be available on the project webpage on a later date.

The current energy transition leads to the utilization of new more intermittent energy solutions, a large-scale addition of new users, and new requirements for grid stability. This leads to the implementation of new and enhanced smart infrastructure, such as smarter energy grids, require enhanced use of data and new smart solutions to ensure reliable operation. This requires new solutions for communication within the energy sector, of which 5G is one opportunity. 5G can enhance the grid in the themes of grid control and data collection. This includes use cases in enhanced grid protection, distribution automation and the control and forecasting of renewable production. The opportunities that 5G provides for drone services can also aid in grid inspection and maintenance. The main question that remains is if enhanced mobile communications are a requirement for a fairly static infrastructure sector. Still, 5G has clear benefits when the number of smart devices that provide data to utilities, service providers, and consumers increases substantially, and opportunities in network slicing provide dedicated channels for integral safety operations via the Ultra Reliable Low Latency Communications (URLLC) slice. Examples of possible use cases are identified in the table below:

Table 16. Possible use cases of 5G within smart energy infrastructure.

Use Case	Additional Information
Distribution automation	5G can provide guaranteed low latency for fault location, isolation and grid protection. In addition, 5G can be utilized to monitor equipment and loads connected to the grid widely and on a ultra-low latency.
Predictive Grid Maintenance	5G can provide opportunities for using drones in maintenance operations
Load Balancing, Control and Forecasting of renewables	Increase of renewable generation leads into a more complicated grid where the number producers grows numerous and energy flows bidirectionally. 5G can aid in the control, monitoring and forecasting of these assets while ensuring reliable communication from these assets themselves.
Enhanced Smart Meter Usage	5G can ensure high capacity while the number of smart devices and the amount of collected data increases. This, in turn, can aid in providing more value from the smart meters utilized in Finland by for example providing real-time information to consumers and creating services to increase flexibility by altering consumer behavior.

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The feasibility study also aimed to assess the different service opportunities that a 5G ecosystem can provide for a smarter energy sector. To link this assessment to the Kera district, services previously identified in the Kera-based Neutral Host Pilot project were utilized. The project identified five different service clusters for a smart city enhanced with a local 5G network. From these five clusters, 16 services were identified to have a link to the energy sector within this report. These opportunities are related to the sharing of data, optimization of energy services, provision of information and guidance, monitoring, and visualization. The services partly correlate with the use cases mentioned above. The correlating opportunities include ones related to the real-time control of renewables, data monitoring and visualization, and drone services.

The final aim of the report in relation to the energy sector was an identification of the key stakeholders within a 5G ecosystem. From the literature review, five different sectors were identified for different stakeholders. These were infrastructure operators, industry and research, policymakers and standardization, service providers, and users. A rough idea of the different stakeholders that fit under these different profiles is given in the final report that will be provided publicly on the SPARCS website at a later date, and a more detailed look on what stakeholders can be identified within Espoo will be added.

Action E12-2	**5G as service enabler. Developing new service models for autonomous transport and e-mobility linked to the local 5G network, solutions enabling the use of car batteries as energy reserve and the operation of autonomous transport. (ESP, stakeholders)**
Detailed plan	Identify smart infrastructure requirements for autonomous transport and e-mobility. Open discussion with smart city Kera area development, relevant stakeholders and ongoing projects developing autonomous transportation and 5G technologies in Kera (including LuxTurrim5G+ / Neutral Host Pilot -project; Six Cities: Low-carbon transport in mobility hubs -project). Estimate car battery capacity available for energy reserves in different scenarios.
Targeted outcome	Car batteries and smart charging can improve power balance and reduce emissions and costs. 5G technologies can support the use and operation of autonomous transportation and enable e-mobility in local networks.
Roles and responsibilities	ESP: Main responsibility.
Main achievements till M36	Action E12-2 delivered: • Discussions with relevant stakeholders. Assessment of car battery solutions. Assessment of local 5G network in the operation of autonomous transportation. • Stakeholder engagement has continued with a survey done on 5G as a service enabler. • Feasibility study completed with the following learnings: • Smart infrastructure requirements for autonomous transport and e-mobility. • Role of 5G in V2G and AV solutions. The development of autonomous mobility and Vehicle-to-Grid solutions, together with new developments in the utilization of 5G within these services, will be constantly monitored and the literature review will be updated if needed.

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Within the mobility sector, the development of autonomous mobility will require enhanced communications solutions from intra-vehicle sensing systems all the way to long-range communication between the vehicles and everything around them, known as Vehicle-to-Everything (V2X). 5G is an enable to this long-range communication section of autonomous transport development. For the foreseeable future, autonomous vehicles will need an opportunity for human control in unexpected situations. Without new communication solutions, this human control needs to be provided on-site. Another opportunity that 5G provides is network slicing, where a dedicated slice of the 5G network is provided for V2X communications to ensure the reliable exchange of operation-integral data. As with the energy sector, 5G provides the most benefits as a critical mass of autonomous vehicles is reached and the rate of data collection and exchange has increased rapidly. Still, the development of new products and infrastructure within the telecommunications and automotive sectors is a long process, and thus stakeholders in both fields have already begun working on the needed enhancements. A brief overview of the main benefits of 5G for AV's can be seen in the table below.

Table 17. Main benefits of 5G for autonomous mobility.

Benefit	Additional Information
Remote Control	5G can provide an opportunity for remote control of autonomous vehicles in real-time if unknown situations occur
Fast and reliable transfer of time-critical information	Via the utilization of network slicing, the V2X slice can ensure the transfer of time-critical information between the vehicle and the infrastructure, network and other vehicles reliably to enable better traffic flow
Control of a large amount of assets	As the number of smart assets producing, controlling, monitoring, and transferring data within the transportation network increases, 5G can provide the means of scaling up mobile communications to meet the increased demand.

So far, the amount of research on the opportunities of 5G within Vehicle-to-Grid (V2G) solutions has been low. However, some research has still been made within this field. Oftentimes, the role of 5G within V2G has been deemed quite low, as V2G does not have the low latency requirement that autonomous vehicles require. However, the opportunities of 5G for mM2M and mIoT solutions are deemed beneficial for V2G. As eV fleets scale up, 5G can ensure reliable communication. Still, current state-of-the-art research mostly centralizes on communication within the charging station, and does not consider communication needs for mobile EV's. This research often focuses vehicle-to-infrastructure communication (V2I) and autonomous vehicles (AV's), which do not consider grid connection as extensively as other issues, such as safety. Within 5G, network slicing can be used to provide reliable communication solutions to the charging infrastructure as the amount of chargers increases. In addition to network slicing, the added possibilities of edge computing as a 5G service can provide the processing power needed nearby the eV users. Edge computing is proposed as an

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interesting innovation for EV's due to the high mobility of the vehicles themselves, in addition to the EV-situated computing power needed to make decisions on charging and discharging based on user preferences and grid condition. These decisions also need to be made in real-time due to the nature of electricity trade, thus providing a need to construct a communication network that minimizes delay in V2G communication.

From the analyzed research, an intent to overlook V2G when piloting 5G solutions for mobility can be seen, as V2X and autonomous mobility are much more viable options for research in the sphere of 5G and mobility. However, the role of 5G within the enhancement of V2G communications can be substantial as the amount of eV's in circulation increases. Still, the full role of 5G is only seen as the implementation of the V2G services continues.

To gain further insights on the opportunities provided by 5G to the mobility sector, a questionnaire towards stakeholders in current 5G projects was devised. The included projects are as follows:

- LuxTurrim5G
- Neutral Host Pilot
- SPARCS
- 5G-Safe-Plus
- Smart and Clean Kera
- 5G-Force
- 5G Finlog
- ARPA
- Smart Otaniemi ecosystem

The questionnaire included the following questions:

- How important would you say the implementation of a local 5G network is for the advancement of mobility services?
- Within this question, you can freely add your thoughts on the role of 5G within the development of mobility in the near future.
- What are the major benefits that a local 5G network could bring to the providers of mobility services?
- What are the major benefits that a local 5G network could bring to the users of mobility services?
- What are the major benefits that these mobility services enhanced by 5G could bring to the cities and to the built environment?
- What are the major risks to take into account when implementing a local 5G network?
- What kind of mobility services and type of businesses could be developed in connection with local 5G at this time?
- What about in 30 years, what are the possibilities after further development of the technology?
- What new actors or working procedures do we need to advance the development of 5G within smart cities even further?
- What is, in your opinion, the city's role in developing the local 5G network and connected mobility services?

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- What do you think the role of the city could be in the future, once the local network has been developed and is being utilized for smart mobility services?

The fully anonymous survey received a total of 12 answers, which was a lot less compared to the approximately 60 recipients of the original e-mail. However, as this was an expert survey, it was still deemed beneficial to analyze the provided answers. The analysis will be provided in the full report. As with the energy sector, the possible service opportunities were analyzed, and stakeholders were mapped. From the previous reports provided by local projects, 14 service opportunities were identified. This only includes the opportunities identified under the mobility service cluster, and other opportunities under other clusters can have uses within the mobility sector as well. The stakeholder mapping identified the same five major divisions as the previous analysis in E12-1, and Espoo-based stakeholders will be added at a later date.

In short, 5G can be seen as an auxiliary technology that enables mobile communication at the needed latency requirements even when the number of smart devices increases substantially. The opportunity of 5G to provide network slices for different communication requirements ensures reliable time-critical communication between actors in both the energy and mobility sectors. In addition, the research and development done within Espoo 5G development projects on data platforms and marketplaces can aid in the development of future opportunities and services on the sharing of data between sectors, of which several have already been identified during these previous projects. However, more work still needs to be done on identifying the most crucial and interesting future 5G-based services for development, and possible operator models for local 5G networks and data marketplaces need to be developed further to identify the best options.

Action E12-3	**Blockchain technology as enabler. Enabling energy transfer and tracking in bi-directional power grids (electricity and heat) with the use of blockchain technology.**
Detailed plan	Conduct literature study and compile blockchain models globally Create SWOT table for blockchain utilization in Kera Propose blockchain model for electrical and thermal energy transactions and flexibility aggregation in Kera Estimate costs and benefits Investigate legal barriers Ref: Action E16-2 blockchains for city-wide DSM.
Targeted outcome	Cost-efficiency and uptake of distributed power and heat generation is enhanced if prosumer model is streamlined and automatic. Blockchains ensure prosumer model transparency and verification functionality.
Roles and responsibilities	ESP: Overall coordination. VTT and Siemens: technical support. Stakeholders
Main achievements till M36	Action E12-3 delivered: • A literature study was conducted and blockchain model architecture was compiled and explained • A SWOT table for blockchain utilization in Kera was completed

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	• Blockchain solutions for electrical and thermal energy transactions and flexibility aggregation in Kera were analyzed • Costs and benefits were identified • Legal barriers were investigated Opportunities on implementing the identified pilots during future activities will be constantly monitored, and results are reviewed and discussed according to the devised roadmap. The landscape around the blockchain technology will be monitored and the literature review will be updated if needed.

4.4 Smart Building Energy Management

Action E6-3 about Smart Building Energy Management demonstrates how domain knowledge and real-time monitoring of elevators, escalators and people flow enables the creation of novel data sources to be employed in modern Smart Building Energy Management systems.

The aim of this task was on technological enablers and collaborative development activities to achieve low-latency and robust methods of data integration. As a result, the created solutions can also be seen to reduce the need for additional physical meters and other costly sensors, while providing additional value from the existing equipment.

Action E6-3	**Solutions in Smart Building Energy Management. The activity demonstrates how elevators, escalators, and people flow intelligence solutions, could be utilized in smart building energy management and demand response via interoperability with energy management system through APIs. Aim to reduce peak demand.**
Detailed plan	1. Define technical architecture 2. Define algorithm and software specification 3. Validate technical performance in development environment 4. Test data communication performance between building management and KONE devices 5. Use communicated data of KONE devices in smart building energy management system, for example, to momentarily supply more power from an on-site battery bank or to reduce consumption of other appliances when an elevator is accelerating in order to limit the power demand peak visible to the electricity grid and verify the desired effect.
Targeted outcome	Enabling solutions for elevators, escalators and people flow intelligence solutions to interlink with building energy management systems to provide additional value to the building owner/operator, especially in the form of power demand forecasting.
Roles and responsibilities	KONE: Algorithm and software development in KONE devices, which allow real-time communication with building energy management systems. Installation/updating of required KONE components in the pilot building(s)

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	SIE: Read the transferred KONE data and showcase its applicability in making smarter decisions for building energy management and demand response (Sello): Testbed for implementing the on-site communication system with high-end monitoring and control capabilities on Siemens platform
Main achievements till M36	Action E6-3 delivered: • Elevator power demand forecast system to reduce building level peak power: • Data transfer test and verification in development environment • Data transfer test with an actual on-site elevator • On-site peak demand reduction test and analysis • Power demand–based people counting solution for escalators and moving walks
Outlook (post M36)	Analyzing the business potential of the peak shaving solution in different building types and under special circumstances, such as during emergency power conditions, continues within SPARCS and as direct collaboration between KONE and Siemens. Furthermore, the benefits power demand–based people counter solution are to be further studied with potential customers.

Within E6-3, KONE has developed an algorithm that can forecast the short-term (~30s), high-resolution (1-s) power demand of selected elevators. The algorithm has been implemented as a software running on KONE devices and its functionality has been tested with on-site elevators. Furthermore, considerable improvement in the power demand model was achieved during the SPARCS project, allowing more accurate results throughout the KONE elevator portfolio, enabling increased scalability of the solution.

In order to employ the elevator power demand forecast, it needs to be communicated to the building automation system in real-time. Due to the intermittent nature of elevator power demand, the communication delay needs to be minimized, necessitating on-site communication or edge computing. Therefore, KONE and Siemens agreed on the communication protocol and datapoints to be transferred in the early phases of the SPARCS project work.

After the successful implementation of the power demand forecasting solution in KONE premises, the solution was taken into the field – the selected elevator group located in the Sello shopping center. In Sello, the communication between the KONE solution and Siemens platform was established, after which an air-handling unit was set to be controlled based on an algorithm interpreting the received elevator power demand forecast. The performance of the system is being tracked and to be further analyzed during the monitoring period of the SPARCS project. Figure 65 illustrates the real-time elevator group power forecast and the power demand of the controllable air-handling unit. The impact of the applied control method is visible in the declining power demand of the air-handling unit when the elevator power demand is forecasted to increase during the next 30 seconds. Fine tuning of the control and forecast algorithms continues during the SPARCS monitoring period.

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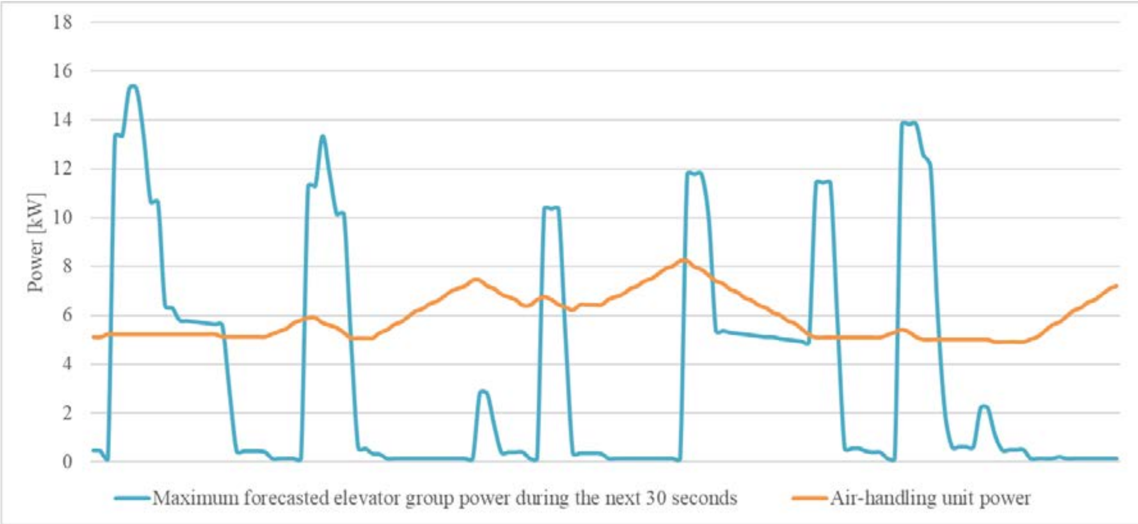

Figure 65. Impact of low-rise elevator group power demand forecast on the controlled air-handling unit with the measurement setup in Sello with allowed control range of 50–100% of rated power. (Source: KONE)

According to KONE internal analysis and energy expert interviews conducted as part of SPARCS, the short-term elevator power demand shaving has limited customer value in low-rise buildings due to the relatively small power required to move the low-speed elevators, while can help mitigating peak power tariffs in high-rise buildings having multiple high-speed elevators, especially in the future with the increase of real-time, measurement-based pricing. The solution can also prove valuable in emergency power systems, in which the backup power supply limits the total connected instantaneous power demand to a specific power range. This value proposition will be under detailed analysis during the monitoring and replication phases of the project.

The part of the task referring to escalators and people flow intelligence was in minor scope during the task due to their limited impact on peak power. Nonetheless, the power demand data of the 13 escalators connected to the Siemens platform provide a strong basis for understanding the role of elevators and escalators in the total building energy consumption. Moreover, KONE studied the performance of power demand based–people counting on the escalators. The approach provides realistic evaluation of the people flows in all of the 13 monitored escalator and moving walk devices, while reducing the need for additional sensoring for people counting. The accuracy of the model is under analysis during the monitoring period. Figure 66 demonstrates the results of the applied algorithm.

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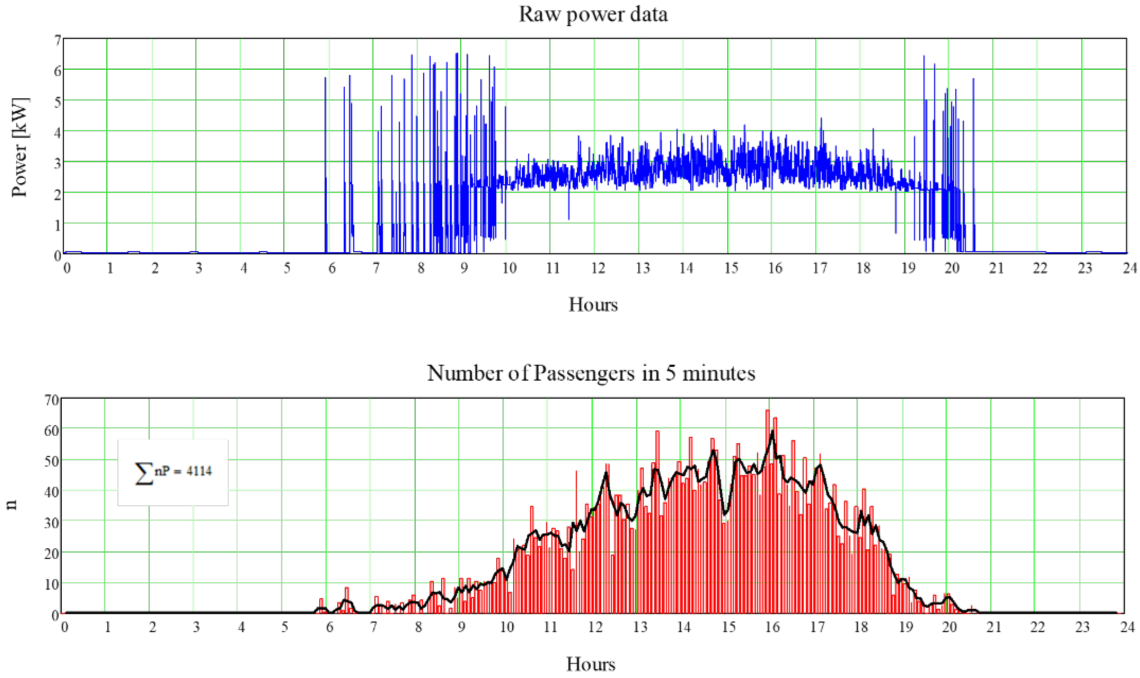

Figure 66. Intermittent-operating escalator power demand profile (1-second resolution) obtained from Siemens platform and passenger numbers (5-minute resolution) derived by the KONE algorithm over one full day. (Source: KONE)

With the help of SPARCS partners and learnings during the monitoring period, the aim is still to better understand the value and benefits which the detailed knowledge of people flow and occupancy in the building could bring for Smart Building Energy Systems.

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5 PLANNING OF POSITIVE ENERGY DISTRICTS IN ESPOO

5.1 Introduction to task 3.5

The task *T3.5 Planning of Energy Positive Districts* focuses on the development of urban planning methodologies for smart city development.

When planning a positive energy district, different aspects (such as: the geographical location of the district and its properties, the renewable energy environment, population, energy consumption behaviour, costs and regulations) need to be considered. Data rich 3D city models not only support urban planning in obtaining a greater understanding of given urban opportunities and challenges, but also provide benefits during the planning and implementing process of PED solutions. One important aspect when developing PEDs is the improvement of the energy performance of the already existing building stock. Three-dimensional illustrations of the existing building stock can help to recognize potential buildings, that are e.g. in need of an energy renovation. 3D models may also enable the development of comprehensive urban energy strategies, by localizing energy saving potentials but also by visualizing and simulating bigger building blocks or districts.

The successful implementation of PEDs is not only depending on the availability of technical solutions, but also on social, political and business commitment. The energy transition is a multi-level phenomenon and in order to develop smart and truly sustainable cities or energy systems the social dimension needs to be addressed upfront and throughout the whole development process.

5.2 Energy Positive District Planning

The subtask *3.5.1 Energy Positive District Planning* is divided into three actions that aim to support the development and the implementation of tools for energy positive block development (mainly action E17-2) and new models and methodologies for smart city planning (mainly action E22-1). Action E20-1 focuses on identifying smart building requirements for the Finnoo district with the aim to replicate local energy solutions. Activities within the subtask 3.5.1 go beyond project month M36 and will continue until M60. While action E20-1 is covered in Deliverable D3.3, results from action E17-2 and E22-1 are described in more detail in the following paragraphs.

Action E17-2	CityGML as a tool for energy positive block development. Starting 2019, The City of Espoo offers an open, and public, Espoo 3D City model. The model covers all of Espoo and all objects included are described in the CityGML standard, except for bridges and tunnels. The action implements the MODER tool using Apros simulator and City GML integration, for assessing the potential for energy positive blocks in Espoo. The methodology has been developed in the H2020 project MODER, Mobilization of innovative design tools for refurbishing of buildings at district level (Innovation Action, EeB-05-2015).
Detailed plan	This action studies in practice, how CityGML could be integrated in the planning and development of energy positive blocks, local energy production and energy efficiency of buildings. This action includes:

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	• Formulate the selection criteria for choosing a suitable area. The defining factors are e.g. the availability of data and its level of detail. (For the new areas data might be not available.) (ESPOO, VTT) • Identify a suitable mixed-use area, which will act as a reference site with the adequate level of detail in CityGML. Potentially, the district could be Kera or Finnoo. If another site is chosen, opportunities may later be exploited in Kera to support PED development. (ESPOO) • Espoo will provide data related to the identified district in CityGML format. Espoo will check and improve the semantics of the data provided in the CityGML, to include e.g., construction year, building use, heating and cooling type, number of occupants, ventilation heat recovery, etc. In case of seasonal storage - possibly geometric description in CityGML). • Identify a set of technologies to support local PED development, including energy efficiency improvements and distributed energy generation opportunities. The related objectives for the energy solutions will be formulated. (VTT, ESP) • Establish a design scenario portraying positive energy block solutions (VTT, ESP) • Carry out block level 12-month simulation using Apros simulator and City GML integration, using both a cold winter and warm winter scenario. (VTT) • Optional: If seasonal storage is included, estimate time needed for storage patterns to stabilise. (VTT) • Calculate On-site Energy Ratio for all scenarios (VTT) • Optional: assessing CAPEX and OPEX. carbon emissions. • Assess opportunities revealed by the 3D data to fast-track such technologies (ESP) • Visualising the results (VTT, ESP) • Engage with stakeholders to validate processes (ESP) • Document the process described above (ESP, VTT)
Targeted outcome	New development sites differ in geographies, building stock and local energy sources, so there is no one-size-fits-all model for a district energy solution. This work aims to clarify how CityGML could support low carbon urban planning and block/district level energy analysis. This work can also provide a good practical use case for collecting and incorporating needed building and energy related semantics into the CityGML. Geographic and building data combined with energy simulation results allow not only for technical assessments but also -when combined with cost data- for economical assessments. Such assessments based on local specifics can help in all kinds of decision-making processes.
Roles and responsibilities	ESP: Identify Kera, Finnoo or another suitable district in Espoo, and provide data related to the identified district in CityGML format, check and improve semantics of the data. VTT, ESP: Identify baseline energy solutions and propose new positive energy block solutions. VTT: Carry out required analysis as specified above ESP, VTT: Engage with stakeholders to validate results

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Main achievements till M36	Action E17-2 delivered: • criteria for selecting a suitable site were defined • a mixed-use area including seven buildings in the area of Espoonlahti was chosen • data related to the chosen site were collected and provided • a set of technologies and measures to support local PED development was selected for the analysis • a block-level 12-month simulation was performed • on-site energy ratios were calculated for each scenario • the simulated results were visualized on a map • the results were presented to stakeholders within the City of Espoo The methods and the results of the analysis are described in more detail after this table.
Outlook (post M36)	There are no further analyses planned to be made after project month M36. However, modelling results will be validated and discussed furthermore to evaluate how these results can support future development work related to the city's 3D model and energy data base.

This work aimed to clarify how CityGML could support low carbon urban planning and block/district level energy analysis. At the beginning, the following criteria were considered when choosing a suitable site for the CityGML analysis:

- site to be of interest for the City of Espoo
- several buildings to be located in the area of interest (more than one building needed for the analysis)
- preferably the site incorporates the use of renewable energy sources (e.g. solar energy)
- data provided in the CityGML to include e.g. construction year, building use, heating and cooling type, number of occupants, ventilation heat recovery

Considering the criteria above, the Espoonlahti sports park was selected as suitable site (Figure 67). Within this site seven buildings of different building type were selected, which are: two schools, a kindergarten, a swimming hall, an ice hockey arena as well as a rescue and fire facility. All the buildings are connected to district heating. Figure 68 shows part of the CityGML attribute list for one of the buildings, as well as the presentation of the building in 3D format. Once the site was selected, the buildings' data from the existing public 3D city model as well as additional data on annual energy and water consumption were collected and

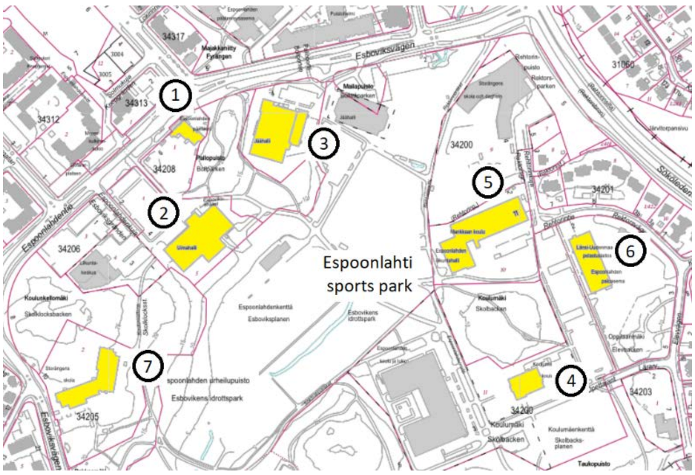

Figure 67. Selected buildings within Espoonlahti sports park (Source: City of Espoo)

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provided to VTT. Next a set of technologies and measures supporting the local PED development were identified.

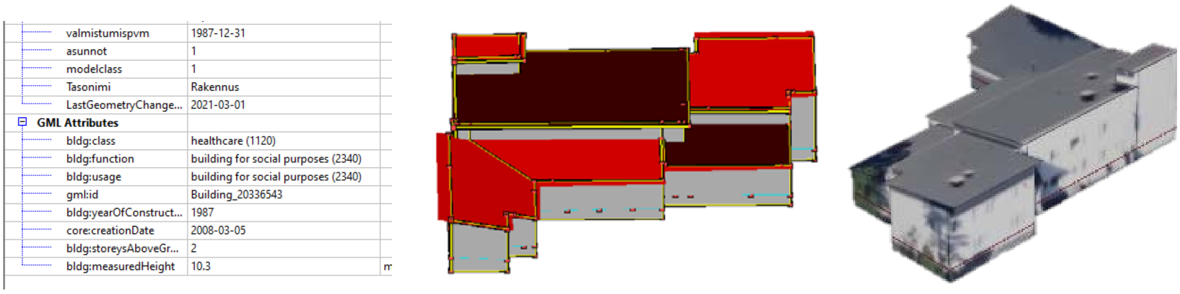

Figure 68. CityGML attribute list and example of a building of the Espoolahti sports park visualized with Trimble Locus based on Espoo's open data. (Source: City of Espoo)

The following technologies supporting local PED development were identified:

- energy efficiency improvement measures
  - energy efficient windows (all buildings, except ice hockey arena)
- distributed energy generation
  - rooftop PV (all buildings)
  - geothermal energy and heat pumps for heating (swimming hall)
  - standalone PV installations

Simulation methodology

To carry out a block-level 12-month simulation, a simplified building energy consumption model implemented in Apros software was adapted as python scripts to be run from QGIS python console to visualize the results on map. The simplified model requires only a very limited set of parameters: construction year, building use (type), building gross floor area, and number of floors.

These parameters for the buildings are contained in the CityGML files provided by the city of Espoo. The simulation tool converts these inputs into a larger set of calculation variables characterizing buildings' typical shape, occupancy and ventilation profiles, areas and insulation properties of building envelope components, common domestic hot water consumption, etc.

The accuracy of the results obtained using weather conditions of the test reference year for some of the building types (e.g., schools) were good (within 10% of measured), but for some of the buildings such as swimming hall and ice hockey arena – the difference was significant. This is due to the fact that these buildings are rather special and can't be directly modelled by the closest supported building type ”sports hall”. The procedure needed further development to include specifics of such special buildings.

As yearly and for some buildings also monthly metered consumption was available, the adopted approach was to separate the measured consumption into explained by the model and non-modelled. In order to perform the separation, first, an attempt is made to obtain the simulated consumption close enough to measured by modifying occupancy-related model parameters. These include, for example, slight changes in heating temperature set points, daily occupancy schedule, hot water consumption or similar but not those describing structures or ventilation equipment. In case these

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modifications failed to bring simulation consumption close enough to measured, the remaining consumption difference was considered unexplained and was attributed to certain purely operation-related processes taking place in buildings. This non-modelled consumption remains the same irrespectively of the changes made to building model – for example, heating swimming pool water, non-standard building operation (children's hobbies, sports, various courses, etc.) and use of non-typical devices.

In order to assess performance of building-level and area-level improvement measures, a set of indicators is used. The indicator calculation for the buildings and the block as a whole included on-site energy ratio, on-site energy fraction and on-site energy matching for electricity and heat. The calculations are based on the framework proposed by Cao et al. (2013)[5].

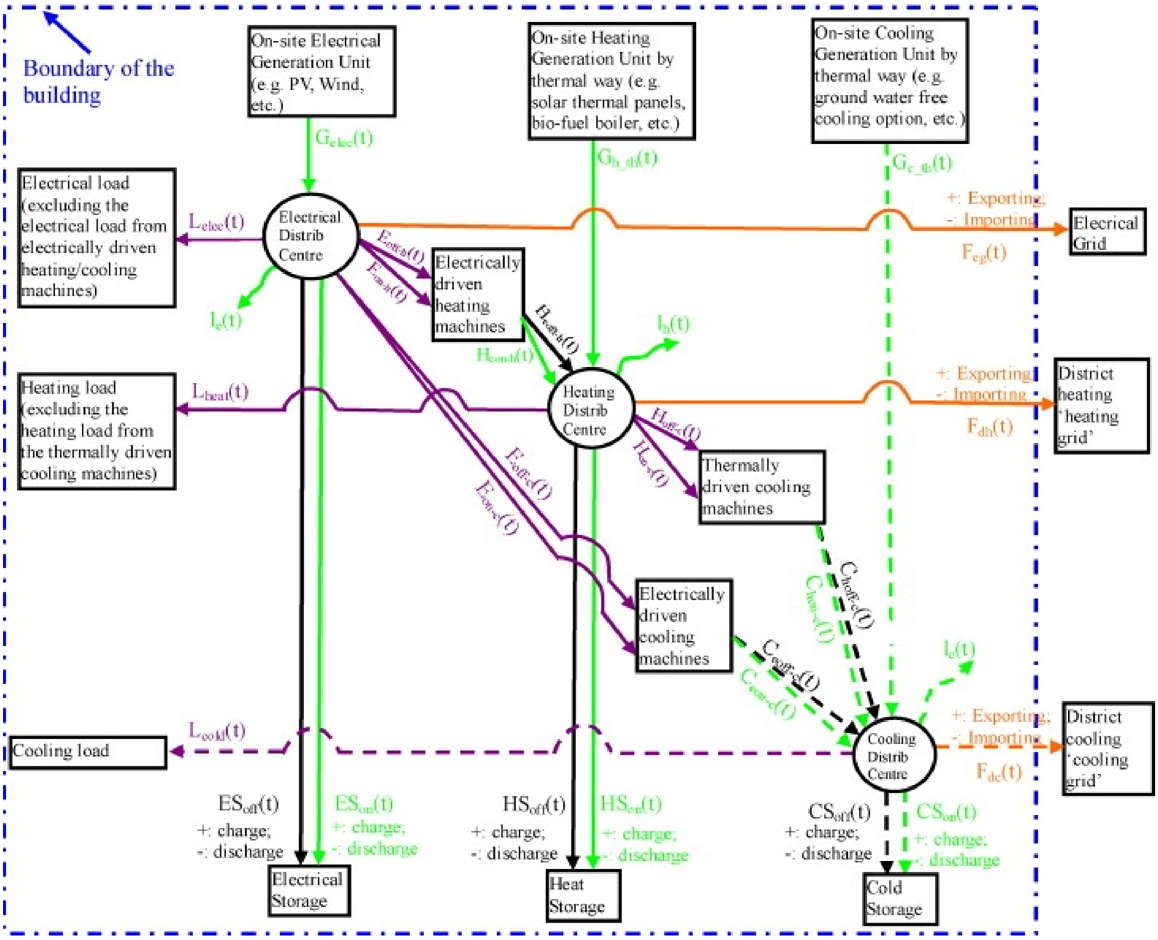

Figure 69. Topology of the indices proposed by Cao et al. (2013)

The figure shows components of energy balance: electrical and heating loads (L_{elec}, L_{heat}), on-site electricity generation (G_{elec}), exchange with electricity distribution and district heating networks (F_{eg}, F_{dh}). The only type of energy conversion is represented by heat pumps ("electrically-driven heating machines") which consume electricity (E) and produce heat (H). There is neither cooling nor energy storages in the area. The

[5] Cao S., Hasan A., Sirén K., 2013, "On-site energy matching indices for buildings with energy conversion, storage and hybrid grid connections", Energy and Buildings, Vol. 64, Pages 423-438, https://doi.org/10.1016/j.enbuild.2013.05.030

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indicator calculation framework envisages special treatments for conversion machines. In particular, the energy extracted by ground-source heat pumps from the ground is considered local heat produced on-site. On-site part of electricity used by heat pumps also counts as on-site heat production. The aggregation on area level sums buildings' loads and generation, so any possible local energy excesses and shortages are settled within the area.

The results of simulated building energy consumption include:

- domestic hot water consumption
- space heating consumption
- hot water circulation losses
- electricity consumption associated with lighting and other appliances typical to building use.

These simulated values are compared with measured total heating and electricity consumption as well as estimated domestic hot water consumption (from measured water consumption).

Table 18. Measured and simulated specific consumption of electricity, total heat including domestic hot water and domestic hot water, kWh/(m² · a).

		before separation			after separation		
	Consumption	**measured**	**simulated**	**error, %**	**simulated**	**non-modelled**	**error, %**
Daycare	**Electricity**	85,2	45,9	46,1	45,9	40	-0,9
	Total heat	276,7	163,9	40,7	204,9	70	0,7
	-of which DHW	28,8	11	61,8	28	0	2,7
Swimming hall	**Electricity**	171,7	51,1	70,2	51,1	120	0,3
	Total heat	634,9	179,9	71,7	369,9	265	0
	-of which DHW	217,9	20	90,8	210	0	3,6
Ice hockey arena	**Electricity**	371,5	51,1	86,2	51,1	320	0,1
	Total heat	68,6	198,2	-189,1	204,4	-136	0,2
	-of which DHW	0	20	-	0	0	-
School 1	**Electricity**	56,6	45,9	18,9	40,2	16	0,7
	Total heat	137,3	154,5	-12,5	147,3	0	-7,2
	-of which DHW	8,6	11	-27,7	9	0	-4,5
School 2	**Electricity**	59	45,9	22,1	45,9	13	0,1
	Total heat	159	159,8	-0,5	152,8	0	3,9
	-of which DHW	4,1	11	-169	4	0	2,2
Fire rescue and maintenance	**Electricity**	113,8	131,4	-15,5	131,4	-18	0,3
	Total heat	345	321,1	6,9	334,9	0	2,9
	-of which DHW	11,3	40	-255,5	11	0	2,2
School 3	**Electricity**	101,8	45,9	54,9	45,9	56	-0,1
	Total heat	207,8	151,2	27,2	162,9	45	-0,1
	-of which DHW	11,4	11	3,3	11	0	3,3

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Table 18 summarizes the results of the process for the seven considered buildings.The total floor area of buildings is 25472 m2 and estimated specific heating and electricity consumption amounts to ca. 270 and 151 kWh/m^2.

Energy efficiency improvement measures – energy efficient windows

After the separation of modelled and non-modelled components of consumption, the building models can be used to estimate the impact of energy efficiency improvement measures. One of the identified measures to improve the buildings' energy efficiency is the replacement of the old windows in all buildings, except at the Ice hockey arena, with new ones, having a U-value of at least 0.8 W/(m²·K). The change in the annual heat consumption before and after the replacement of the windows is summarized in Table 19. The overall reduction of heat consumption in the whole district (including the seven buildings) is estimated to be 5.5 percent.

Table 19: Annual total heat consumption in buildings before and after potential window improvement (MWh/year)

	before measures	window improvement	change, %
Daycare	222,9	207,6	-6,9
Swimming hall	3365,0	3275,4	-2,7
Ice hockey arena	311,2	311,2	0,0
School 1	284,8	250,5	-12,0
School 2	974,4	860,2	-11,7
Fire rescue and maintenance	917,6	865,0	-5,7
School 3	782,3	713,9	-8,7
Total	6858,1	6484,0	-5,5

Although the improvement measure leads to energy saving, the on-site energy indicators remain the same as before measures, as no energy is produced on the site.

Distributed energy generation – rooftop PV installations

Another measure that was simulated after the window improvement is the installation of solar panels to produce electricity locally. The assumption is that for all buildings 80 per cent of the buildings' roof area is used for PV panel installation. The total roof area of buildings was 15010 m^2.

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Table 20. Estimated annual electricity production of PV panels, MWh/year, in case 80 percent of buildings roof area is used for PV panel installation. On-site energy indices.

	Electricity generation	Electrical loads	Electricity from grid	OERe	OEFe	OEMe
Daycare	29,3	69,7	40,4	0,42	0,32	0,76
Swimming hall	191,6	906,8	715,2	0,21	0,21	0,99
Ice hockey arena	328,9	1687,8	1358,9	0,19	0,19	0,99
School 1	69,9	108,7	38,7	0,64	0,39	0,60
School 2	230,6	375,8	145,2	0,61	0,39	0,64
Fire rescue and maintenance	99,1	310,7	211,6	0,32	0,25	0,77
School 3	136,1	383,6	247,5	0,35	0,29	0,81
Total	1085,5	3843,0	2757,5	0,28	0,26	0,92

Comparison of OERe and OEFe reveals that OEFe is usually lower than OERe – this means that the output of PV panels at times exceeds own loads and is being exported to the grid. The vales of the matching index (OEMe), which become lower than 1 also show the same. On the area level, the results of the measure is that ca. 28% of electricity loads are covered by own production, ca. 26% could be used on-site simultaneously with production and ca. 8% of generated electricity was exported to the grid.

Distributed energy generation - Semi-deep geothermal energy in swimming hall

All the selected buildings of the area are connected to district heating and no on-site heat production takes place. One of the opportunities to produce heat on site is the use of semi-deep geothermal installations. Their operation was simulated using pyg-function tool constant assuming monthly heating loads of the swimming pool (measured data). The installation consisted of 30 coaxial borehole heat exchangers with depth of 800 meters. The boreholes were assumed to be situated equally-spaced along a circle having a radius of 90 meters centered at the swimming hall. The main dimensioning criteria were heat power and energy self-sufficiency and long-term operation of the borehole field. The latter was achieved by requiring that the temperature of water returning to borehole field is always above zero degrees Celsius over the period of 50 years. The hourly simulated temperature of fluid entering the borehole field is presented on Figure 70.

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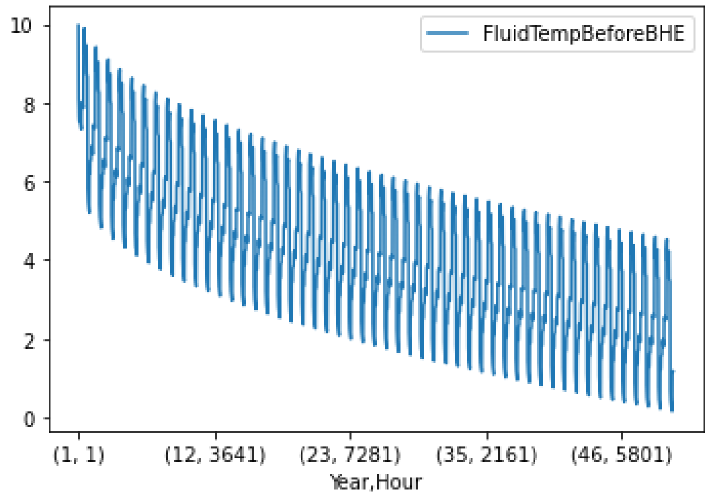

Figure 70. Hourly simulated temperature of fluid returning to the borehole field from heat pumps over 50 years operation period. (Source: VTT)

The results for the area with improved windows, rooftop PV and geothermal installation in swimming pool are shown in the table below.

Table 21. Estimated annual electricity production, electricity consumption of building and heat pump, heat output of heat pump (MWh/a).

	Electricity generation	Electrical loads	Heat pump electricity	Electricity from grid	Heating loads	Heat pump output
Daycare	29,3	69,7	0,0	40,4	207,6	0,0
Swimming hall	191,6	906,8	785,2	1500,4	3275,4	3501,1
Ice hockey arena	328,9	1687,8	0,0	1358,9	311,2	0,0
School 1	69,9	108,7	0,0	38,7	250,5	0,0
School 2	230,6	375,8	0,0	145,2	860,2	0,0
Fire rescue and maintenance	99,1	310,7	0,0	211,6	865,0	0,0
School 3	136,1	383,6	0,0	247,5	713,9	0,0
Total	1085,5	3843,0	785,2	3542,7	6484,0	3501,1

The operation of the heat pump nearly doubles electricity consumption of the swimming hall and notable increases it in the whole area. At the same time in terms of heating production, the swimming hall may even have some surplus ($OER_h > 1$), but on-site energy ratio for electricity drops from 0.21 to 0.11, see Table 22.

The on-site energy indices for electricity and heat are summarized in Table 22.

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Table 22. on-site energy indices for electricity and heat for buildings of the area. (Source: VTT)

	OERe	OEFe	OEMe	OERh	OEFh	OEMh
Daycare	0,42	0,32	0,76	0,00	0,00	1,00
Swimming hall	0,11	0,11	1,00	1,07	0,75	0,88
Ice hockey arena	0,19	0,19	0,99	0,00	0,00	1,00
School 1	0,64	0,39	0,60	0,00	0,00	1,00
School 2	0,61	0,39	0,64	0,00	0,00	1,00
Fire rescue and maintenance	0,32	0,25	0,77	0,00	0,00	1,00
School 3	0,35	0,29	0,81	0,00	0,00	1,00
Total	0,23	0,22	0,96	0,54	0,44	1,00

The heat pump covers slightly more than a half of the total heat consumption of the area (54%). According to the results, only about 75% of heat pump output was utilized at the swimming hall itself – the value is so low, because due to limitations of geothermal model the heat load was defined as constant monthly loads, while calculation of indices was carried out using hourly values.

Standalone PV installations and further improvements

The on-site energy ratio of electricity of the area, which drops from 0.28 to 0.23 with introduction of geothermal installation at swimming hall, can be improved by additional photovoltaic installations in the area. However, as roofs of the buildings are exhausted, these are assumed as standalone installations. Achievement of 100% on-site energy ratio for electricity would require generation of 3543.7 MWh of electricity per year and installation of ca. 19600 m^2 of module area (and even more surface area for the installations).

In order to achieve 100% of on-site energy ratio for both electricity and heat, another geothermal installation (similar to the one assumed for the swimming hall) could be considered. It would also require additional electricity, which could similarly be offset by additional standalone PV installations. The resulting on-site energy indices for electricity and heat for the area are shown in Table 23 below.

Table 23. Resulting on-site energy indices for electricity and heat for the area. (Source: VTT)

	OERe	OEFe	OEMe	OERh	OEFh	OEMh
Area, before and after window improvements	0,00	0,00	1,00	0,00	0,00	1,00
The above, and installation of rooftop PV (80%)	0,28	0,26	0,92	0,00	0,00	1,00
The above and geothermal installation at swimming hall	0,23	0,22	0,96	0,54	0,44	1,00
The above and standalone PV (19600 m^2 modules)	1,00	0,40	0,40	0,54	0,45	1,00
The above and another geothermal installation (the same as in swimming hall)	0.86	0,375	0,44	1,08	0,78	0,86
The above and additional standalone PV (4500 m^2 modules)	1,00	0,39	0,39	1,08	0,79	0,86

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It may be noticed, that despite achieving on-site energy ratios for both heat and electricity exceeding one, the on-site energy fraction for electricity remains around 0.4 (only 40% of loads are covered by PV panels' output simultaneously with electricity generation). Similarly, the matching index for electricity, shows that ca. 40–45% of PV panels' output is used on-site. These values are to some extent affected by constant monthly profiles associated with geothermal installations.

Visualization of the results

A visualization of results in terms of the indicators for electricity was implemented for buildings using color-coding in QGIS software. An aerial view of the block is combined with 3D building shapes coloured according to indicator value.

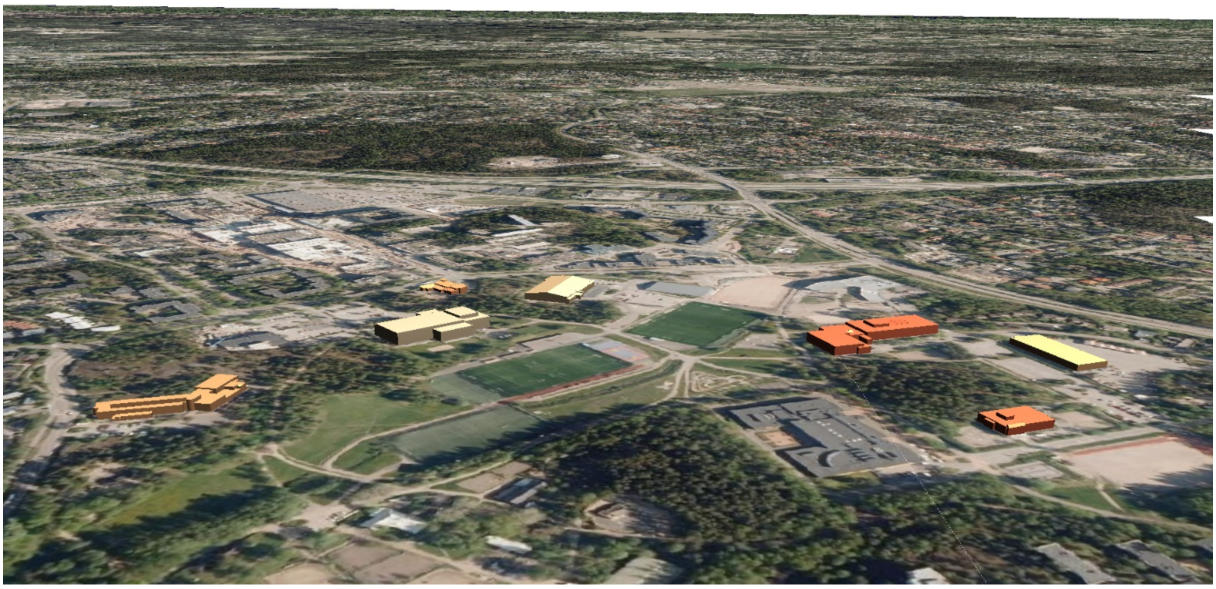

Figure 71. Visualization of results overlaid on a map of the case area (one selected on-site energy ratio for electricity after window improvements). (Source: VTT)

The visualization of the results using maps may help a block planner in assessing how realistic certain improvement measures can be, identify preliminary locations for geothermal and standalone PV installations. However, gradient-based color-coding has its limitations. Also block-level indicators require visualization – this can be done, for example, using text overlaid on the map. Comparison of several scenarios and relative improvements may be made easier using tables, similar to Table 23, combined with appropriate sorting.

Further improvements may include accounting for renewable or non-fossil fuel shares of the energy provided to the area via electricity distribution and district heating networks. These may help account for, among other things, any excess heat available in neighboring areas.

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Action E22-1	Co-creation for smart city development. Co-creation models to support land use planning are developed as a collaboration between industry, SMEs, citizens and other stakeholders to support functional solutions of new development areas regarding e.g. energy, mobility, and service solutions based on digital platforms and fast networks.
Detailed plan	A co-creation model is facilitated by 3rd party subcontracting, which is now under preparation. The model will first be made for Kera and only after that, a more general model for whole city of Espoo.
Outcome	For sustainable smart city development, a co-creation model towards actualization as alliance model is needed to support collaboration and best practices.
Roles and responsibilities	ESP: to tender and choose the service provider for creating these models. stakeholders: to participate in the co-creation process
Main achievements till M36	Action E22-1 delivered: • a tendering process to find a suitable subcontractor was realized • a subcontractor was chosen • a total of four workshops were held in form of Design Sprints • communication and engagement activities were enhanced with the help of steering and sparring groups • regular Coffee Talks have been held to share results and insights of the model's development process • citizens have been involved through a questionnaire and an organized online-event A more detailed description of the co-creation model process, including stakeholder engagement, can be found from Deliverable D3.6. For thematic results on mobility see Deliverable D3.5.
Outlook (post M36)	M39 More general model for City of Espoo finalized: the model will be further elaborated on, and it will be fitted to suit different kind of areas in Espoo (and beyond). In general, the development work will continue up to December 2022, when the final model will be ready and available on a separate web page (https://co-creatingsparcs.fi) for open use. In addition to the visualized model, the process will also result in a virtual toolkit for supporting the development of sustainable and smart urban areas. M40-M60 Internal work, communication to introduce models to different stakeholders in city organization, as well as outside the city organization.

To create new approaches for smart city planning that could also take into consideration PEDs, the City of Espoo conducts a process to create a "co-creation model" for sustainable and smart urban areas.

The main goal of the co-creation model is to present ways and tools on how to develop urban districts as sustainable and smart city areas in co-operation between the city organization, companies, educational institutions, research institutes, other organizations and associations, and citizens. Instead of developing separate solutions within city districts, the model aims towards a more holistic approach to city planning, where smart and sustainable solutions are developed together as integrated, interacting and supporting parts within smart city areas, forming a larger smart city

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ecosystem. Developing such a smart city area as a whole required new tools, practices and processes of co-creation and dialogue to connect the different stakeholders, builders, investors, policy makers, organizations and citizens together in the city planning. This process covers the whole life cycle of the area from the initial planning to the in-depth design, construction, and use and operation phases.

The co-creation model development process is a service design process, comprising of a series of case project reviews, workshops, questionnaires, webinars, and other activities that have been directed to different stakeholders. The aim is to co-create the co-creation model with the relevant stakeholders from the very beginning.

A co-creation model for sustainable and smart urban areas – Key insights about energy solutions

The co-creation model focuses on the themes of energy, mobility & urban services, and nature & green-and-blue infrastructure (including land use development), which all have a significant impact on the City of Espoo's goals of becoming carbon-neutral by 2030. In this deliverable the focus lies on presenting the key insights about energy solutions. For more details about the model and the work in general, see Deliverable D3.3 and D3.6 (on the co-creation process and engagement activities through which the model was developed with different stakeholders). The E-mobility aspects of the co-creation model are described in more detail in Deliverable D3.5.

As part of the co-creation model development process, citizens have been reached by conducting an online survey during February-March 2022. While the survey produced valuable information about the citizens' perspectives on smart city and sustainable city development, responses concerning energy issues were negligible. In general, it can be concluded that mobility and nature / urban green spaces are the topics that the survey's participants were most concerned about. Perhaps Espoo's citizens do not perceive energy as a topic they can have influence on. The survey was shared via the social media network (Facebook) of the City of Espoo and received 118 responses.

One of the main challenges identified during the co-creation development process in the context of energy is how to engage different actors in the best way and make them commit to contribute to overall sustainability goals. During the workshops, which were held together with different stakeholders during spring 2022, key process elements and methodologies were developed and identified to address this challenge (see the Figure below).

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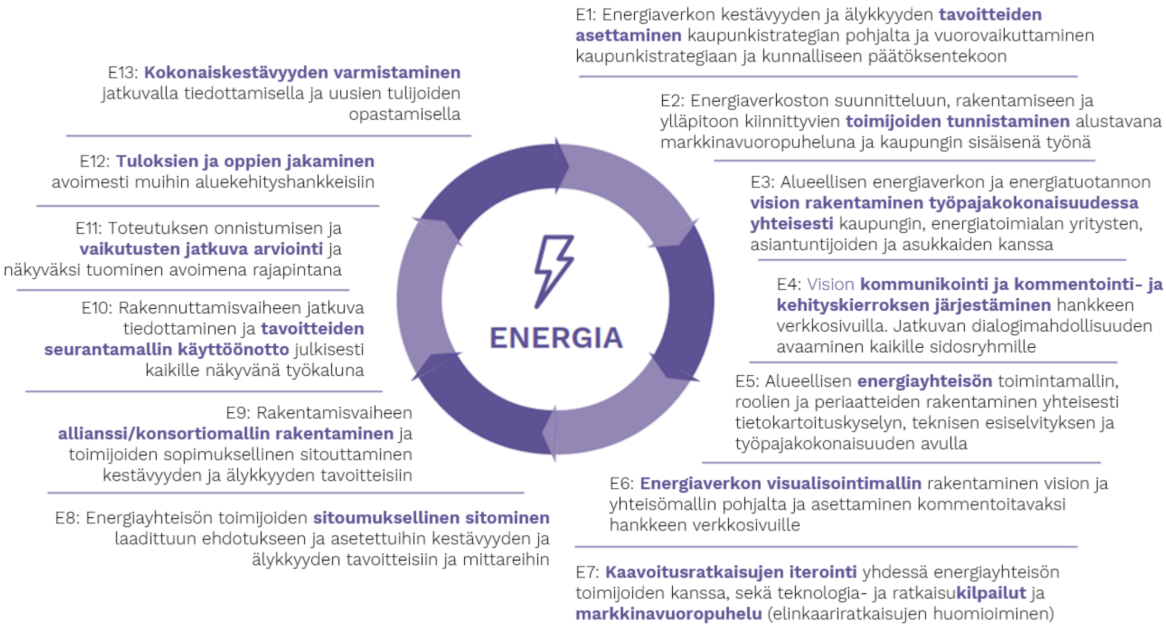

Figure 72. Concrete steps of co-creation identified during the workshops that were held together with different stakeholders during spring 2022 (WSP Finland & Korkia Consulting, 2022). The steps are explained in the text below.

The following concrete steps for a successful co-creation process related to energy were identified:

- E1. **Setting targets** for the sustainability and intelligence of the energy network based on the city strategy; in interaction with the city strategy and the municipal decision-making.
- E2. **Identifying the actors** involved in the design, construction and maintenance of the energy network through an initial market dialogues and internal work within the city.
- E3. **Building a vision** for the regional energy network and energy production **in a series of workshops** with the city, energy companies, experts and residents.
- E4. **Communicating the vision** and organising a **feedback and development** round on the project website. Creating the opportunity for an ongoing open dialogue for all stakeholders.
- E5. Building and defining the operating model, roles and principles for a **local energy community** jointly through surveys, a preliminary technical study and a series of workshops.
- E6. Creating a **visualisation model** of the energy network based on the vision and community model and making it available for comments on the project website.
- E7. **Iterating city planning solutions** together with the actors of the energy community, as well as technology and solution **competitions and market dialogues** (taking into account life cycle solutions).
- E8. Entering into a **binding agreement** with the energy community actors about the developed proposal and the set sustainability targets and indicators.

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E9. Building an **alliance/consortium model for the construction phase** and forming a contractual commitment with the actors about sustainability and smartness objectives.
E10. Continuous communication during the construction phase and **introducing a monitoring model**, which is visible to the public (e.g. via a tool).
E11. **Continuous evaluation of the success** and the impact of the implementation phase; and making it visible via an open interface.
E12. Open sharing of results and lessons learned with other regional development projects.
E13. **Ensuring overall sustainability** through continuous information and guidance for new actors.

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6 CONCLUSIONS

The objective of this report was to present from an energy point of view all of the demonstration actions that are realised by SPARCS in the city of Espoo, Finland by the end of the third project year. At beginning, an overall summary of the Lighthouse demonstrations in Espoo is presented, and then continue summarising the details in the demonstration areas. The demonstration actions cover broadly various low carbon improvements of urban area development, including buildings, energy systems, transportation, urban planning and citizen involvement. Some of these aspects are covered in other parallel deliverables, e.g. D3.3, however from other perspective.

Demonstration activities embark a range of solutions supporting transition towards low carbon areas and testing of possibilities for positive energy blocks in Espoo. The activities include energy efficiency improvements, smart energy management, e-mobility, ICT, utilizing local RES production, citizen involvement and urban planning. Many of the activities challenge the old ways of working, enhancing the collaboration at the municipality, companies, citizens, research, and collaboration networks. Sites for the demonstration activities are the Sello shopping centre and surrounding buildings at the centre of the Leppävaara district and the Lippulaiva block in the Espoonlahti district. The Kera district provides an additional demonstration site, focusing on low carbon urban planning and developing processes, and approaches for positive energy blocks.

Demo Lippulaiva

The construction of Lippulaiva shopping center has been completed and the mall operates since April 2022. Its heating and cooling demand is mainly covered with an on-site geothermal heat pump system (among the largest of this kind in Europe) but a district heating connection and electric boilers as a back-up heating system and for peak heat demand are existing too. Electricity demand is covered with PV panels (roof) and certified renewable electricity. The energy consumption and production are smartly controlled and participating in the Nordpool's reserve markets is assessed. The idea is to follow a day-ahead market price for electricity and participate in reserve market with battery storage. Simultaneously, the smart electricity control service should cut peak loads and gain savings in electricity costs.

The study on 2-way DH indicated that in spite of many simplifications and uncertainties in the analysis, the profitability of selling the excess heat to the district heating network would be challenging with available selling tariffs.

Demo Sello

Smart energy solutions for self-sufficiency in the Leppävaara center are in the focus. Sello's thermal energy processes are modelled to understand the potential increased energy efficiency, self-sufficiency, and thermal flexibility. The potential is realized by providing the thermal flexibility to local district heating company Fortum. Increasing the self-sufficiency through deep heat geothermal well is evaluated using the Power System Simulator PSS.

The goal of the activities was to create messaging interface between the Siemens building management system (BMS) and Fortum heat plant automation, send the

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required flexibility calls via the new interface and adjust the heating demand based on the calls. The solution is now implemented as a pilot project in the Shopping centre Sello. The created solution includes flexibility forecast and the actual demand response request sent by Fortum. The required actions are made by Siemens BMS, which adjusts the required flexibility based on the consumption at the time.

The system was tested first time in the winter 2020–2021. The experiences and data collected during the heating season were analyzed during the summer. Some minor program adjustments were implemented to the BMS before the next winter to improve the operations. The adjustments showed clear improvements during the next winter. In 2021 the total peak heating power demand was 11.4 MW and in 2022 the peak was 7.7 MW. This is a drop of 32% in peak power need. The peaks in 2022 are around 30% lower than in 2021. Also, the highest demand take place typically between 13.00 and 19.00 in 2022 whereas the peaks were earlier between 11.00 and 14.00 in 2021. The high demand has therefore shifted 2–4 hours later.

This kind of behavior is very desirable since high power peaks may cause firing up of backup heat plants which are usually based on gas and oil. Instead, the more consistent consumption allows the actual heat plant to operate with better efficiency and use more renewable heat sources. The more buildings and the more heating systems are connected to the demand side management, the higher potential for flattening the demand curve exist and the required response of an individual system can be smaller. Consequently, the CO2 emissions and dependency on fossil fuels will be significantly lower than without demand side management.

City planning

City planning for positive energy blocks is about the development and the planning of positive energy blocks. Mainly focus was on exploring the possibilities to utilize tools (such as the Espoo's 3D city model) in the development and the planning of new areas, but also on how to find energy infrastructure solutions and develop guidelines that enhance the uptake of such solutions. Also new options for demand side management in Espoo generally was explored.

3D city models have become common geospatial data assets for cities as they can be utilized in numerous fields and tasks related to e.g. city planning, visualization, and decision-making. Within SPARCS the City of Espoo explored the benefits of using 3D city models in pursuing new opportunities and implementing solutions for PEDs. The main findings of this study have been published in the report "The role of 3D city models in PED development", which can be found from the sparcs.info webpage (Juslin, The role of 3D city models in PED, 2021).

The City of Espoo also examined different opportunities offered by energy community legislation and new cost-efficient renewable energy generation and distribution technologies. The work gives an overview of the existing regulations on energy communities, including a short literature review on existing research networks and projects related to energy communities. The report also contains information about three energy community case examples, which were studied as part of a case study. Lastly, the potential to form an energy community in the developing Kera district was assessed and presented in the report. Also assessed were possible business models for the electricity, heating, cooling and fuel sectors in the context of the Kera district.

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Current and new business models were mapped, and the suitability of different models to the Kera area was explained.

Smart and sustainable district heating holds great potential to reduce emissions. Compared to other heating options, district heating not only enables energy recycling but also energy storage through the district heating network. They provide flexibility not only with power-to-heat storages but also by optimizing the heat usage and production. Artificial intelligence – driven district heating together with demand side management (DSM) – play and important role in the climate challenge and help shaving thermal peak loads and save emissions. To estimate the amount of emissions avoided with the help of the DSM scheme, a detailed energy and DSM flexibility analysis was performed for 8 selected buildings. The analysis was based on recorded hourly values for the years 2019–2021. The results quantify energy savings and avoided emissions.

ICT demonstrations

The EU is moving from centralized electricity generation in power plants operated by large utilities towards a mix of decentralized and often renewable energy production in small facilities. This change in energy sector combined with electrification of mobility and heat creates a new challenge to power grids. Virtual Power Plants are a critical element in this transition and are enabled by digitalization. The energy sector is expected to benefit from blockchain technology. Objective of one of the activities in SPARCS is to enable sector coupling and increase the interoperability, monitoring and control of various energy systems by ICT between smart buildings, smart grid and district heating and cooling systems, EV charging infrastructure, and the allocation of open data.

Models for building automation data were researched in Sello commercial center to help with making data more usable and having more context for the data in machine readable form, which would allow creating more intelligent, scalable, and interoperable programs that would not need manual mapping of data between systems. Also for Sello, the first architecture BIM model was done from drawings of building, later a 3D laser scanned point cloud was created from selected technical rooms in Sello. The point cloud was then connected to the Architecture BIM Model and they were combined together to help with creating BIM model from Building Automation devices (that didn't have good up to date drawings). This enabled BIM model to be modelled with enough accuracy for existing building without good drawings and be built by people who were not familiar with the building and didn't have physical access to the building.

In-depth data analysis was done for electricity, water and heating meters to look for anomalies and root causes in consumption of these mediums. Effects of outside temperature, holidays and number of visitors were taken into account. The three targets "flexibility down", "flexibility up" and "instant power reference" are now forecast with a prediction horizon of 24 hours from a seven-day history of those three time series together with temperature and holidays as provided external data / forecasts (both history and future values are provided for temperature and holidays) and some synthetic helper series for time of day, time of week and time of year. Finally, we now consider the Sello forecasts practical enough so that they can be used for iterating on the end-to-end process and user experience.

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The Sello virtual twin was created

A Virtual Twin makes it possible to visualize selected energy or HVAC near real-time or historic data by 3D BIM based virtual model. The data can be measured (e.g. heating energy consumption, exhaust air temperature) or calculated (e.g. heat recovery efficiency). From a visualisation point of view, it is possible to show average, minimum or maximum values in different part of the building (e.g. in HVAC system zones or spaces). This 3D BIM based visualization makes it possible to check e.g. that in which part of the building selected variable (e.g. heating energy consumption) was too high or too low in selected time (now, last spring, etc.). It is also possible to utilize the virtual twin when optimizing local energy use or detecting and locating energy related faults from studied building. That also includes predicting next day energy consumption and production and 3D BIM based monitoring and visual analysing energy & HVAC data.

BlockChain

With a unique opportunity of working with partners that have an interest in the business of blockchain technologies within the energy sector, SPARCS provides an opportunity for investigating blockchain as a solution for the energy field both locally and internationally. To achieve this, a feasibility study was developed to substantiate any benefits that blockchains offer compared to business as usual within the selected themes of VPP’s and Demand Response (DR).

Smart energy services

Modern energy services can be provided more efficiently, flexibly and reliably if they are based on an appropriate ICT platform. 5G technology is an established global standard for mobile connectivity, and it enables the control of a high number of appliances. From the analyzed research, an intent to overlook V2G when piloting 5G solutions for mobility can be seen, as V2X and autonomous mobility are much more viable options for research in the sphere of 5G and mobility. However, the role of 5G within the enhancement of V2G communications can be substantial as the amount of eV’s in circulation increases. However, the full role of 5G is only seen as the implementation of the V2G services continues.

Activities about Smart Building Energy Management demonstrated how domain knowledge and real-time monitoring of elevators, escalators and people flow can be employed for smarter decision making and demand response actions by the building energy management system. KONE has developed an algorithm that can forecast the short-term (~30s), high-resolution (1-s) power demand of selected elevators. The algorithm has been implemented as a software running on KONE devices and its functionality has been tested with on-site elevators. In Sello, the communication between the KONE solution and Siemens platform was established, after which an air-handling unit was set to be controlled based on an algorithm interpreting the received elevator power demand forecast. The performance of the system is now being tracked and will be further analyzed during the monitoring period of the SPARCS project.

PED planning

This work aimed to clarify how CityGML could support low carbon urban planning and block/district level energy analysis. To carry out block-level 12-month simulation, a

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simplified building energy consumption model implemented in Apros software was adapted as python scripts to be run from QGIS python console to visualize the results on map. The simplified model requires only a very limited set of parameters: construction year, building use (type), building gross floor area, and number of floors. These parameters for the buildings are contained in the CityGML files provided by the city of Espoo. After the separation of modelled and non-modelled components of consumption, the building models can be used to estimate the aggregated impact of energy efficiency improvement measures, e.g. replacement of energy efficient windows or rooftop PV installations in the building stock in the city. A visualization of results in terms of the indicators for electricity was implemented for buildings using color-coding in QGIS software. An aerial view of the block is combined with 3D building shapes coloured according to indicator value.

To create new approaches for smart city planning that could also take into consideration PEDs, the City of Espoo conducts a process to create a “co-creation model” for sustainable and smart urban areas. Developing such a smart city area as a whole required new tools, practices and processes of co-creation and dialogue to connect the different stakeholders, builders, investors, policy makers, organizations and citizens together in the city planning. This process covers the whole life cycle of the area from the initial planning to the in-depth design, construction, and use and operation phases.

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7 Acronyms and Terms

AMR	annual mismatch ratio
ABTM	activity-based transport model
API	application programming interface
BIM	building information model
CAPEX	Capital expense
CHP-bio	combined heat and power production using bio fuels
CityGML	City Geography Markup Language
CCS	Cable charging spot
DH	district heating
DHW	domestic hot water
DSM	demand side management
EV	electrical vehicle
HVAC	heating, ventilation and air conditioning
IoT	Internet of Things
KPI	key performance indicator
NZEB	nearly zero energy building
OEF	on-site energy fraction
OEM	on-site energy matching
OER	on-site energy ratio
OPEX	operating expense
PED	positive energy district
PV	photovoltaic
P2P	peer-to-peer
RES	renewable energy source
RH	relative humidity
RMSE	The root-mean-square deviation
TSO	transmission system operator
VPP	Virtual Power Plant
V2G	vehicle to grid

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8 REFERENCES

Airaksinen, J., Annala, S., Bröckl, M., Honkapuro, S., Lassila, J., Manninen, J., . . . Värre, U. (2019). *Selvitys sähkön omatuotantoon, energiayhteisöihin ja energiahankkeiden lupamenettelyihin liittyvistä kysymyksistä.* Valtioneuvoston selvitys- ja tutkimustoiminta.

Bruegel. (2019). *THE EUROPEAN UNION ENERGY TRANSITION: KEY PRIORITIES FOR THE NEXT FIVE YEARS.* Retrieved from https://www.bruegel.org/sites/default/files/wp_attachments/Bruegel_Policy_Brief-2019_01.pdf

De Filippi, P., & Wright, A. (2019). *Blockchain and the Law.* Cambridge, Massachusetts: Harvard University Press.

Ekoälykylä. (n.d.). *Mustikkarinne: 1000 asukkaan ekoälykylä Kirkkonummen Masalaan*. Retrieved 09 01, 2021, from https://www.ekoalykyla.fi/

Elenia; VTT. (2021). *Energiayhteisökäsikirja.* Elenia.

Espoon Asunnot Oy. (2021). *Hallituksen toimintakertomus ja tilinpäätös 2021.* Retrieved August 02, 2022, from https://www.espoonasunnot.fi/sites/default/files/2022-08/Espoon%20Asunnot_hallituksen%20toimintakertomus_ja_tilinpaatos_2021.pdf

EUROPEAN COMMISSION . (2022, May 18). REPowerEU Plan. Brussels, Belgium. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2022%3A230%3AFIN&qid=1653033742483

European Solar thermal Industry Federation. (n.d.). *SOLAR DOMESTIC HOT WATER PREPARATION*. Retrieved 09 01, 2021, from http://www.estif.org/st_energy/technology/solar_domestic_hot_water_heating_sdhw/

Finlex. (2013, August 9). *Sähkömarkkinalaki 9.8.2013/588*. (Finlex) Retrieved July 16, 2021, from https://www.finlex.fi/fi/laki/ajantasa/2013/20130588#O3L9

Fortum. (n.d.). *Fortum suunnittelee Espoon Keraan ainutlaatuista alueellista energiaratkaisua, josta toivotaan kansainvälistä konseptia*. Retrieved 09 01, 2021, from https://www.fortum.fi/media/2021/06/fortum-suunnittelee-espoon-keraan-ainutlaatuista-alueellista-energiaratkaisua-josta-toivotaan-kansainvalista-konseptia

Helen. (n.d.). *Vuokraa aurinkopaneeli Messukeskuksesta*. Retrieved 04 08, 2022, from https://www.helen.fi/aurinkopaneelit/aurinkosahko/messukeskus

Horn, H., & Mäkinen, J. (2022). *Business models for generation, aggregation, storage, and distribution.* sparcs.info.

IEEE. (2018). *Modeling of Electric Vehicles as Movable Loads inComposite System Reliability Assessment.*

Juslin, A. (2021). *Technical, Economic and Regulatory Barriers for PEDs.* Espoo: sparcs.info. Retrieved August 30, 2022, from https://sparcs.info/sites/default/files/2022-08/E10-1_Technical%20Economic%20Regulatory%20Barriers%20PED.pdf

Juslin, A. (2021). *The role of 3D city models in PED.* Espoo: sparcs.info. Retrieved August 30, 2022, from https://sparcs.info/sites/default/files/2022-08/E10-1_Role%20of%203D%20city%20models%20in%20PED%20development.pdf

Juslin, A., Mäkinen, J., & Horn, H. (2022). *Energy Communities in Positive Energy Districts - Case Kera.* Espoo: sparcs.info. Retrieved August 30, 2022, from https://sparcs.info/sites/default/files/2022-08/E10-1_Opportunities%20By%20Energy%20Communities.pdf

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 864242
Topic: LC-SC3-SCC-1-2018-2019-2020: Smart Cities and Communities

KSS Energia. (n.d.). *Vuokraa aurinkopaneeli*. Retrieved 04 08, 2022, from https://kssenergia.fi/vuokraa-aurinkopaneeli

Mäkinen, J. (2022). *Blockchain Solutions for the Energy Sector: a SPARCS Feasibility Study.* Espoo: sparcs.info.

Meteotest AG. (n.d.). *meteonorm*. Retrieved 09 22, 2022, from https://meteonorm.com/en/

Nordpool. (n.d.). *Nordpoolgroup*. Retrieved 09 20, 2022, from https://www.nordpoolgroup.com/en/Market-data1/Dayahead/Area-Prices/FI/Monthly/?view=table

Sørensen, Å. L., Lindberg, K. B., Sartori, I., & Andresen, I. (2021). *Analysis of residential EV energy flexibility potential based on real-world charging reports and smart meter data.*

Sung, J. (2019). How Digitalisation Is Modernising Energy Efficiency. *European Energy Innovation*. Retrieved from https://www.europeanenergyinnovation.eu/Articles/Autumn-2019/How-digitalisation-is-modernising-energy-efficiency

The Consumers' Union of Finland. (n.d.). *Sopimukset: Ostaminen ja kuluttajansuoja*. Retrieved 04 21, 2022, from https://www.kuluttajaliitto.fi/materiaalit/sopimukset/

WSP Finland, & Korkia Consulting. (2022, April 26). *Design Sprint 3: Kohti älykkään ja kestävän kaupungin.* Retrieved August 24, 2022, from https://co-creatingsparcs.fi/wp-content/uploads/2022/05/Esitys_Design-Sprint_3_26042022.pdf

Blockchain:

Fingrid; Ministry of Economic Affairs and Employment of Finland, “Lohkoketjuteknologia Osana Älykästä Sähöjärjestelmää,” 2018.

The committee of future development of the Finnish parliament, “katsaus lohkoketjuteknologioiden hyödyntämiseen suomessa,” Helsinki, 2019.

Energy Web Foundation, “The Energy Web Chain: Accelerating the Energy Transition with an Open-Source, Decentralized Blockchain Platform,” 2019.

J. Backman, K. Valtanen, A. Laikari, V. Vallivaara and J. ilomäki, “Blockchain review: BOND project (Blockchains Boosting Finnish Industry) report,” Teknologian tutkimuskeskus VTT Oy, Espoo, 2017.

City of Espoo, “The Espoo Story,” [Online]. Available: https://www.espoo.fi/en/cityespoo/espoo-story. [Accessed 28 04 2022].

Ramboll, “Keran Energiapositiivisen Alueen Energiaekosysteemi,” Espoo, 2020.

World Energy Council, “The Developing Role of Blockchain”.

World Energy Council, “World Energy Insights Brief: Is Blockchain in Energy Driving an Evolution or a Revolution,” 2018.

P. De Filippi and A. Wright, Blockchain and the Law, Cambridge, Massachusetts: Harvard University Press, 2019.

M. Andoni, V. Robu, D. Flynn, S. Abram, D. Geach, D. Jenkins, P. McCallum and A. Peacock, “Blockchain technology in the energy sector: A systematic review of challenges and opportunities,” Renewable and Sustainable Energy Reviews, pp. 143-174, 2019.

E. Mengelkamp, J. Gärttner, K. Rock, S. Kessler, L. Orsini and C. Weinhardt, “Designing microgrid energy markets, a case study: The Brooklyn Microgrid,” Applied Energy, no. 210, pp. 870-880, 2018.

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Topic: LC-SC3-SCC-1-2018-2019-2020: Smart Cities and Communities

Energy communities:

J. Airaksinen, S. Annala, M. Bröckl, S. Honkapuro, J. Lassila, J. Manninen, J. Partanen, T. Rautiainen, M. Saario, J. Vanhanen and U. Värre, “Selvitys sähkön omatuotantoon, energiayhteisöihin ja energiahankkeiden lupamenettelyihin liittyvistä kysymyksistä,” Valtioneuvoston selvitys- ja tutkimustoiminta, 2019

E. Union, DIRECTIVE (EU) 2019/944 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 5 June 2019 on common rules for the internal market for electricity and amending Directive 2012/27/EU, Official Journal of the European Union, 2019.

E. Union, DIRECTIVE (EU) 2018/2001 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 11 December 2018 on the promotion of the use of energy from renewable sources, Official Journal of the European Union, 2018.

Elenia, VTT, “Energiayhteisökäsikirja”.

The Ministry of Economic Affairs and Employment, “A Flexible and Customerdriven Electricity System: Final report by the Smart Grid Working Group,” Publications of the Ministry of Economic Affairs and Employment, Helsinki, 2018.

5G:

J. Hemilä, T. Ryynänen, H. Hämmäinen, S. Vijay ja B. Gholampooryazdi, ”LuxTurrim5G D1.1.1: State-of-the-art analysis,” LuxTurrim5G Consortium, 2017.

P. Ahokangas, M. Matinmikko-Blue, S. Yrjölä ja H. Hämmäinen, ”Platform configurations for local and private 5G networks in complex industrial multi-stakeholder ecosystems,” *Telecommunications Policy,* nro 45, 2021.

S. Borenius, H. Hämmäinen, M. Lehtonen ja P. Ahokangas, ”Smart grid evolution and mobile communications—Scenarios on the Finnish power grid,” *Electric Power Systems Research,* osa/vuosik. 199, nro 107367, 2021.

Neutral Host Pilot consortium, ”State-of-Art Understanding of Neutral Hosts in Smart City Development,” 2021.

Ramboll, ”Keran Energiapositiivisen Alueen Energiaekosysteemi,” Espoo, 2020.

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under Grant Agreement No. 864242
Topic: LC-SC3-SCC-1-2018-2019-2020: Smart Cities and Communities