H2020-LCE-2016-2017

EUROPEAN COMMISSION

Innovation and Networks Executive Agency

Grant agreement no. 731249

SMILE

Smart Island Energy Systems

Deliverable D3.4

Requirements Specification

Document Details

Due date	30 April 2019
Actual delivery date	30 April 2019
Lead Contractor	Samsø Energy Academy, SE
Version	Final rev 0
Prepared by	Jan Jantzen, SE
Input from	SK, SEL, DTI, AAU
Reviewed by	RINA-C
Dissemination Level	Public

Project Contractual Details

Project Title	Smart Island Energy Systems
Project Acronym	SMILE
Grant Agreement No.	731249
Project Start Date	01-05-2017
Project End Date	30-04-2021
Duration	48 months

The project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 731249

Table of Contents

1 Introduction

The scope of this report, according to the SMILE Description of Action (DoA), is to document "(…) the final design of the Samsø installation. The report will particularly include a technical description of the system architecture along with final requirements specifications" (1).

However, the construction phase is almost completed at the time of delivery. Therefore, the report seizes the opportunity to step forward toward the overall control by emphasizing the actual technical specifications. The deliverable thus serves a proactive purpose, namely as a data source for technical models, *demand response* analyses, *control algorithm* design, *life cycle assessment*, *cost/benefit analyses*, and dissemination, as defined in WP5, WP6 and WP9.

The following list summarises the main components of the Ballen marina pilot as stated in the Description of Action (DoA) and in scenario 1 of the SMILE public deliverable D3.1 (2):

- Battery system
- Photovoltaic panels
- Heat pump in the harbour master's office
- Connection points for the boats

The SMILE project co-funded the battery system and 200 connection points, while Samsø Municipality (partner SK) finances the remaining components and their installation (up to 340 connection points). The Samsø Municipality put the following out to tender: the photovoltaic plant, the battery cabin, and the connection points for the boats. The requirements specifications were in Danish, but this report is in English for the benefit of the project partners and external researchers.

This report also specifies further components suitable for *demand response* (tasks 3.6 and 3.7 in DoA). For example, it is useful to know the size (in kW) of the sauna in the service building to accurately schedule the time for switching it ON and OFF. The inventory of flexible components may grow, because new opportunities may appear over time.

Figure 1 shows the marina and some of the flexible components. The battery energy storage system (BESS) is inside a building called the Warehouse. The photovoltaic panels are distributed over three sites within the marina. A new heat pump replaced an electric heater in the harbour master's office. In the area, there are in total 340 connection points for the boats. Each socket contains a *meter* and a *contactor* (a switch).

The technical goal is to exhaust the available solar energy (maximize self-supply). A related goal is to cover as much as possible of the demand by solar energy (maximize self-sufficiency). There are also nontechnical goals, namely to attract more sailors to the marina and to increase Samsø's population.

A single point of connection connects the marina to the public grid. It is in the service building, where the public grid meter measures both incoming energy and outgoing energy. The contracted current is 125 amp. In addition, the distribution network operator (KONSTANT) permits at most 50 kW injected into the public grid. This is to protect the village of Ballen from voltage increases higher than 2.5% of normal.

Figure 2 shows the structure of the overall control system. It consists of three levels. The bottom level is the direct control of components, for instance commands to switch a component on or off. The middle level is a scheduler, which calculates *when* to switch components on or off. The top level is a supervisor that forecasts the energy generation and the energy consumption on a 24-hour horizon. There are two cases for optimization. One case is scheduling flexible loads to match the state of charge of the battery. The second case is scheduling the charge and discharge times of the battery. In both cases the goal is either to maximize the use of solar energy or to minimize the daily cost of operation.

The Appendices provide exact data for the known components. These data can be used to design an optimal control strategy. There are still some unknowns at the time of the delivery — such as the electrical load from the boats and some loads on land.

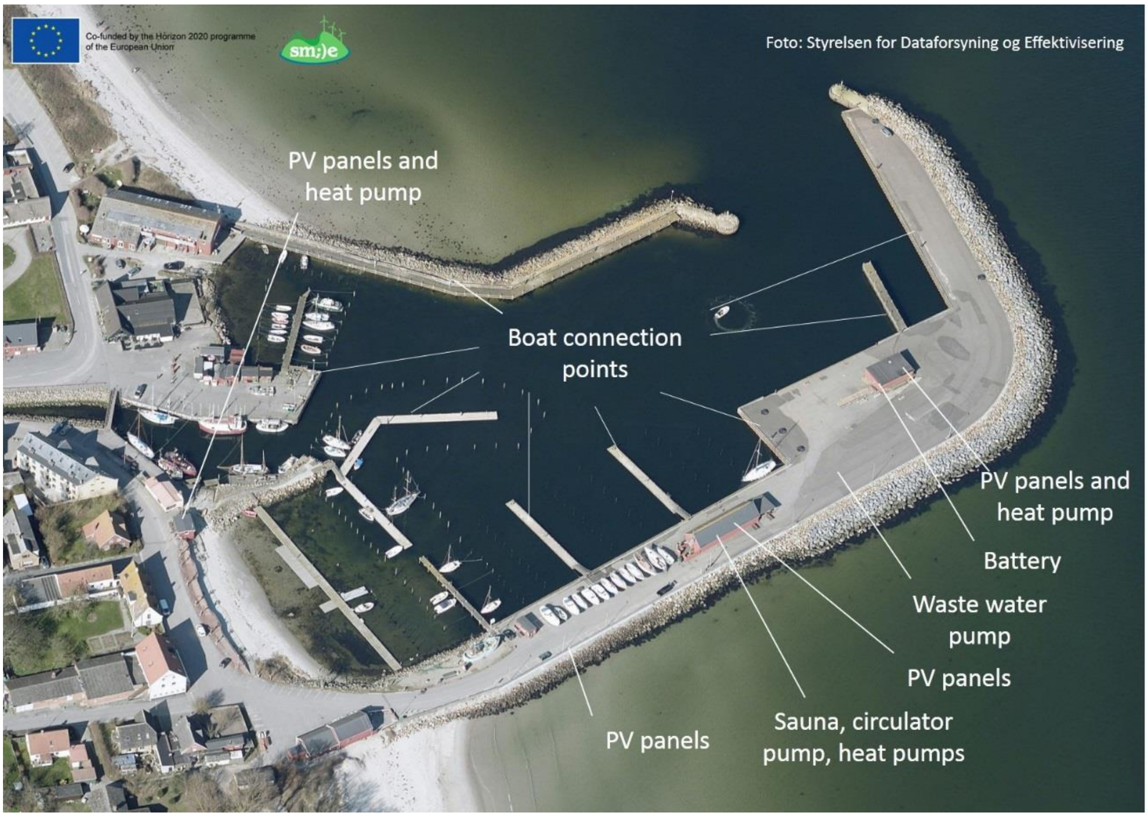
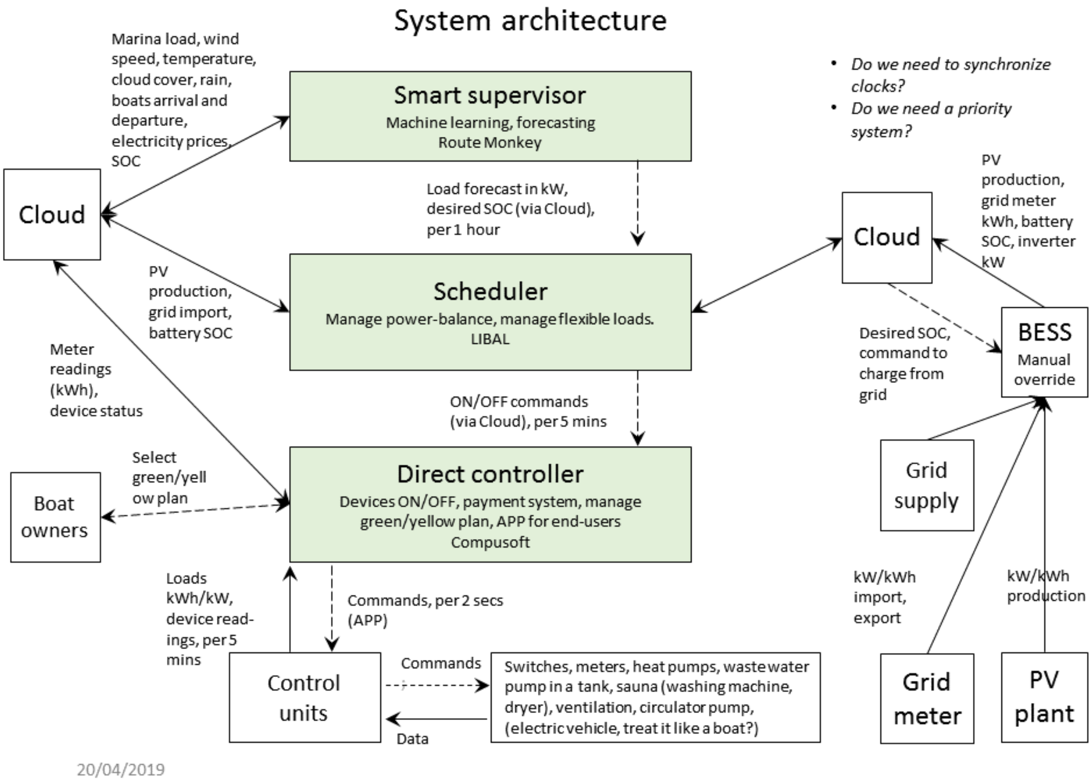


Figure 1. Overview of the Ballen marina and its smart energy components.



20/04/2019

Figure 2. Overall control design.

2 Battery System

This chapter describes the Samsø Battery System. Generally speaking, battery systems connected to the grid are still in a rather early development stage in Denmark. Some formal requirements from the authorities, notably the distribution network operator, are still missing. However, the Danish Technological Institute (partner DTI) has estimated a set of *sufficient recommendations* for installing, connecting, and using a battery system in the Ballen marina.

2.1 Battery cabin

Based on the DTI recommendations the Samsø Municipality invited tenders for a battery cabin. The requirements specification included the following items.

- *Electrotechnical requirements*. The Danish Technical Instruction TF 3.3.1 concerns battery systems and communication, and the installation must comply with TF 3.3.1. The local distribution system operator may have further requirements. The equipment must comply with the Danish standard DS/HD 60364, which is harmonized with EU standards. The cabin must comply with the fire regulations in the 2018 building code for small buildings.
- *Fire hazards*. There are no national requirements or recommendations for battery storages, and usually the local fire authorities are responsible. Fire in a Lithium-Ion battery is unlikely, but should it happen it will be unstoppable. Therefore, the housing should have doors and walls (BS60), dry sprinkler equipment with an outside connection, an alarm system, smoke ventilation, and an outlet for water. It should also have thermal insulation to keep the battery warm during the winter.
- *Human safety*. The battery system should be operated by authorized personnel only. However, the system is fully automated, and no human intervention is necessary under normal operation. The cabin should be locked, declared, and marked as an electric operation site. Yellow warning signs should appear on the outside.
- *Outside connections*. The following connections are necessary: Internet, power supply (3 x 400 Volt AC 80 amp, preferably extendable to 100 kW, 160 amp), auxiliary power (3 x 230 / 400 Volt AC 32 amp), water in case of automatic fire extinguishers, and a drain.
- *Climate*. Dust and droplet trap on incoming air duct, and an air dryer that keeps the relative humidity below 50 %. An air-to-air heat pump will keep the air dry and control the temperature. The required ventilation corresponds to one replacement in 24 hours. It must be possible to ventilate the cabin well in case of thermal runaway in the battery.
- *Ambient temperature*. The recommended maximal indoor temperature is 25 degrees C. For a short duration, 35 degrees are acceptable, but it will degrade the battery. At high load the battery must be at least 15 ^{0}C. During standby, zero degrees is acceptable, but 10 degrees is recommended to prevent condensation on the walls of the cabin. The maximal heat transfer from the battery is estimated at 0.15*50 kW = 7.5 kW (thermal). At normal operation, the heat transfer is less than 3 kW (thermal).
- *Gases from the battery*. The gaseous emissions will be low, but when there are persons inside the cabin, the ventilation should be plentiful.
- *Thermal insulation*. The recommendation is 50-100 mm mineral wool including vapor membrane. The required level of insulation depends on adjacent rooms.
- *Solar irradiation*. It is recommended to avoid direct sunlight to limit the need for cooling. Windows should be of a kind that limits solar influx.

- *Condensation of water*. Condensation on the surface of the battery cells and electrical equipment should be avoided. The relative humidity is to be kept under 50 %.
- *Salt*. The door shall be kept closed, and an air dryer that captures salty droplets is recommended.
- *Internal design*. Control functions should be near the door, and the battery racks in the back of the room. There must be enough space in front of the battery racks for personnel and auxiliary equipment for mounting and demounting battery racks. Wire trays in the ceiling or near the ceiling are recommended for safety. The height from floor to ceiling should be at least 2.3 metres and the floor space at least 8 square metres. The floor must carry the weight of three racks at 600 kg each plus auxiliary equipment. Power electronics must be mounted on fire inhibiting surfaces.
- *Maintenance and monitoring of safety*. There must be a plan for maintenance and regular checks of safety functions, especially the air-drying equipment. There must be a log book that documents events and safety checks.

A company on the mainland (Energy Cool) then designed the battery cabin. The cabin contains three battery racks, an inverter, air conditioning equipment, and cables. The floor of the cabin is rectangular, as Figure 3 shows. The company delivered the cabin on the marina, Figure 4. The roof is water tight, but the cabin fit inside the Warehouse building, out of public view.

APPENDIX A – *Specifications of the battery cabin* provides exact specifications of the cabin.

Figure 3. Computer aided rendering of the battery cabin (Energy Cool). The floor space is 8 square metres.

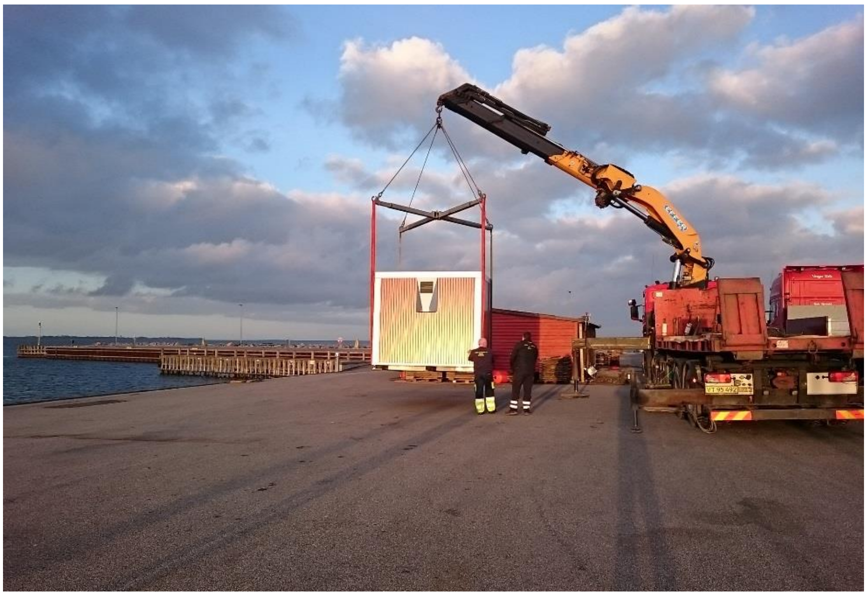


Figure 4. The cabin arrives on the marina. It is now inside the red Warehouse (background).

2.2 Battery energy storage system

The capacity of the battery energy storage system (BESS) is nominally 240 kWh. The size of the battery was determined at an early stage according to the Ballen marina needs and the available budget. To slow the ageing of the battery cells, only 80% of the nominal capacity will be used. In practice, the BESS could be charged to 90% and discharged to 10%, leaving 80% in the middle. Consequently, 192 kWh are available.

The battery can be filled in half a summer day of bright sunshine (by a 60 kWp photovoltaic plant), considering the solar irradiation on Samsø. The size of the inverter is 50 kW, which corresponds to a discharge period of about 4 hours at full load. The actual discharge period will likely be longer when the photovoltaic plant delivers energy in concert with the battery.

Small cells are stacked inside modules, which are themselves stacked in racks. One rack holds eight modules arranged in two columns, and the capacity of a rack is nominally 80 kWh. Therefore, Samsø received three racks to reach the total of nominally 240 kWh. Each rack is encapsulated in a cabinet designed to minimise damages in case of a fire, see Figure 5.

A battery protection unit (BPU) ensures that all cells are charged to the same state of charge (SoC). Furthermore, it protects the battery cells against overcharging — and over-discharging.

A temperature control system inside the cabinet keeps the ambient air temperature steady, preferably around 20 ^{0}C, by maintaining an air flow between the cells. The air intake, and outlet, is at the top of the cabinet, well separated from each other.

A so-called site controller, which is an embedded Linux computer with input/output ports, manages the communication with the battery. The site controller sends status information to a server in the cloud. Conversely, commands from the cloud are executed by the site controller. For example, the state of charge (SoC) is passed to the cloud, and a command to charge the battery is sent back. The cloud thus enables external control of the BESS.

APPENDIX B – *Specifications of the battery energy storage system* contains exact data for further calculations.

Figure 5. Two racks of battery modules.

2.3 Energy storage inverter

The three battery racks operate with direct current (DC), but they are to be connected to the grid, which is alternating current (AC) and three phases. A two-way inverter changes from DC to AC when the battery discharges, and from AC to DC when the battery charges. The inverter must be approved by the electrical grid company to ensure that the voltage quality on the public grid is maintained.

The inverter (ABB model ESI-S) is for three phase networks with or without neutral. It filters harmonics, it compensates reactive power, and it balances the load between the phases. Its maximum nominal power is 50 kW. At most four inverters can be combined, if necessary. Its efficiency is better than 97% at nominal power. The inverter is mounted on the wall inside the battery cabin.

APPENDIX C – *Specifications of the energy storage inverter* contains exact data for further calculations.

3 Photovoltaic panels

The municipality invited several firms to tender for the photovoltaic panels in accordance with local regulations. Table 1 lists the evaluation criteria, and it shows that, apart from the price, efficiency was weighted highly. That is due to land area limitations on the marina. Furthermore, the supplier had to comply with the ISO 26000 standard. The project language is Danish.

Table 2 summarizes the technical requirements that the municipality set. It appears that the plant should be extendable up to 120 kW, which is the simulated maximum guaranteeing a return of investment (deliverable D3.1).

The winning company (Better Energy Solutions) designed a plant consisting of three subsites, named: the marina, the harbour master's office, and the fence. The first site comprises the service building with two separate roof surfaces and the Warehouse. The second site comprises the two faces of the roof on the harbour master's office. The third site is a vertical fence that separates the paved pier from the boulder stones that protect against the sea waves.

Table 1 – Municipal evaluation of tenders for photovoltaic panels.

Evaluation criterion	Weighting
Price	50 %
Total energy efficiency considering the local solar irradiation	30 %
The share of recycled material, and the share of recyclable material	10 %
No materials from the blacklist by the Environmental Protection Agency under the Danish government	10 %

Table 2. Municipal requirements for the PV plant.

Item	Requirement
Dimensioning irradiation for Samsø	1050 W per square metre
Extendability	Max 120 kWp
Performance test	By a third party after commissioning
Product warranty	10 years
90 % performance guarantee	10 years
80 % performance guarantee	25 years
Warranty on inverter	Min 5 years
Lifetime	Min 25 years
Reflecting glare	Not bothersome
Inverter efficiency	At least 98 %
Inverters	Must be on the 'positive list' (Dansk Energi)
Panel efficiency	Min 18 %
Compliance	Standard Test Conditions (STC)
Salt water mist resistance	IEC 61701:2011
Panel colour	Black

The supplier returned documentation based on a simulation package (PV*SOL Premium 2019 R3) that used climate data from the Samsø airport (a grass strip). Figure 6 is an example of a technical drawing from the package.

According to the simulation, the total annual production is 56 000 kWh/year. The total marina demand is about 100 000 kWh/year. It is therefore necessary to buy supplementary energy from the public grid. The number of full load hours is estimated at 935 hours. This is a key figure for the energy production per kWp of PV panels. The number is somewhat lower than normal, but that is to be expected, because some PV panels turn East, some West, and some are mounted vertically. The optimal position is South with a slope of 45 degrees. Figure 7 shows how the PV panels are mounted on the roof of the Warehouse building. That roof surface turns South-East, but the slope is only 20 degrees. The nominal power of the sum of the inverters is 50.5 kW; in practice the power on the AC side is less than 49 kW.

The following three appendices provide exact data for further analyses: APPENDIX D – *Specifications of the marina site PV panels*, APPENDIX E – *Specifications of the harbour master office PV panels*, and APPENDIX F – *Specifications of the fence site PV panels*.

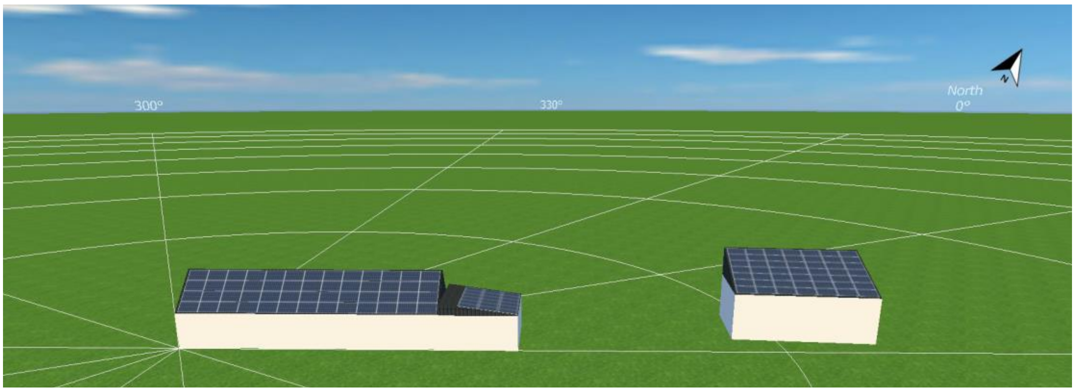


Figure 6. Computer rendering of the 'marina site' (Better Energy, PV*SOL).

Figure 7. A local installer mounts PV panels on the Warehouse building, building 3 of the 'marina site'.

4 Heat pumps

Samsø Municipality (partner SK) invested in a new heat pump for the harbour master's office, see the photo in Figure 8. Because a heat pump provides heat from electricity, it is an important link for a *smart energy* system.

The heat pump replaced the existing electric heater as required in Task 3.3 in the project DoA (1). That saves energy since the heat pump extracts free heat from the outdoor air. It will also be controllable by the overall control system. For example, the control system may preheat the building if there is excess solar energy from the PV plant. In pseudocode, a rule could be,

```
IF (PV production > demand) and (battery is high) THEN start heat pump 15:00 to 17:00
```

The system consists of one outdoor unit (Daikin model RXS25L3V1B) and one indoor unit (Daikin model FVXS25FV1B). The seasonal efficiency (SCOP) is 4.56 and the heating capacity is 3.4 kW (max 2.6 kW electric); it is thus more powerful than the electric panel that it replaced. It can also be used for cooling, and the cooling capacity is 2.5 kW (max 2.5 kW electric). Both the heating and cooling modes comply with energy label A+.

It is possible to add a Modbus gateway for a building management system, which may be relevant in the Samsø case.

APPENDIX G – *Specifications of the heat pump in the harbour master's office* provides details for future calculations.

The Samsø Municipality installed an additional new heat pump in the service building. This was not foreseen initially in the DoA. It has one outdoor unit (Daikin model 3MXS68G3V1B2) and three indoor units (Daikin model 25). In addition, the Samsø Municipality installed a heat pump in the Warehouse building to heat up the new showroom. The heat pump is the same model as the one in the harbour master's office (Daikin RXS25L3V1B outdoor unit, Daikin FVXS25FV1B indoor unit).

APPENDIX H – *Specifications of the heat pump in the service building* provides further details.

Figure 8. A new heat pump (below the roof edge) heats the harbour master's office.

5 Connection points for the boats

When the boats arrive, they plug into a socket equipped with a meter and a contactor. Once they have registered, the contactor opens for the electricity supply, and the meter starts measuring (kWh).

The purpose is to bill each boat for its actual electricity consumption. Previously, all boats paid a fixed amount, but this seems unfair when there is a large difference in the size of boats. Some small boats contain very little electrical equipment, while some large ones are equipped with electric heating, electrical hot water heaters, washing machine, television, communication equipment, and more.

There are 340 metered sockets distributed around the marina. One socket stand contains typically six sockets, and all stands connect to the distribution board in the service building. The distribution board contains 11 groups, and each group is protected by a 50 amp fuse. The fuses set an upper limit on the maximum load on the system.

The meters and the contactors communicate wirelessly with an Internet gateway in the harbour master's office. Each stand contains a radio (XBee) such that all stands together form a local wireless network, which is fault tolerant.

The Samsø Municipality invited several firms to tender for the stands in accordance with local regulations.

APPENDIX I – *Specifications of the connection points for the boats* provides many details about the stands and the sockets. There are 49 stands in total.

6 Other components

Apart from the main components, the Samsø partners wish to include additional components. They are components that provide opportunities to extend the smart energy system. For example, smart control of the sauna heater in the service building could help to balance the solar energy generation and the demand.

6.1 Sauna in the service building

The sauna in the service building is open for the sailors and the public against payment. It is a large electricity load (15 kW), and it shows clearly on the SMILE Dashboard (Figure 9) built by partner Route Monkey. The sauna may be in operation two times per day, but that depends on the day of the week and the demand.

The sauna heater could be used to preheat the sauna when there is excess renewable energy. In pseudocode, a rule could be,

```
IF (PV production > demand) and (battery is high) THEN start sauna 14:00 to 14:30
```

It is also useful to study how long time it takes to heat the sauna (settling time) so that it can be started just in time.

APPENDIX J – *Specifications of the sauna in the service building* provides further details.

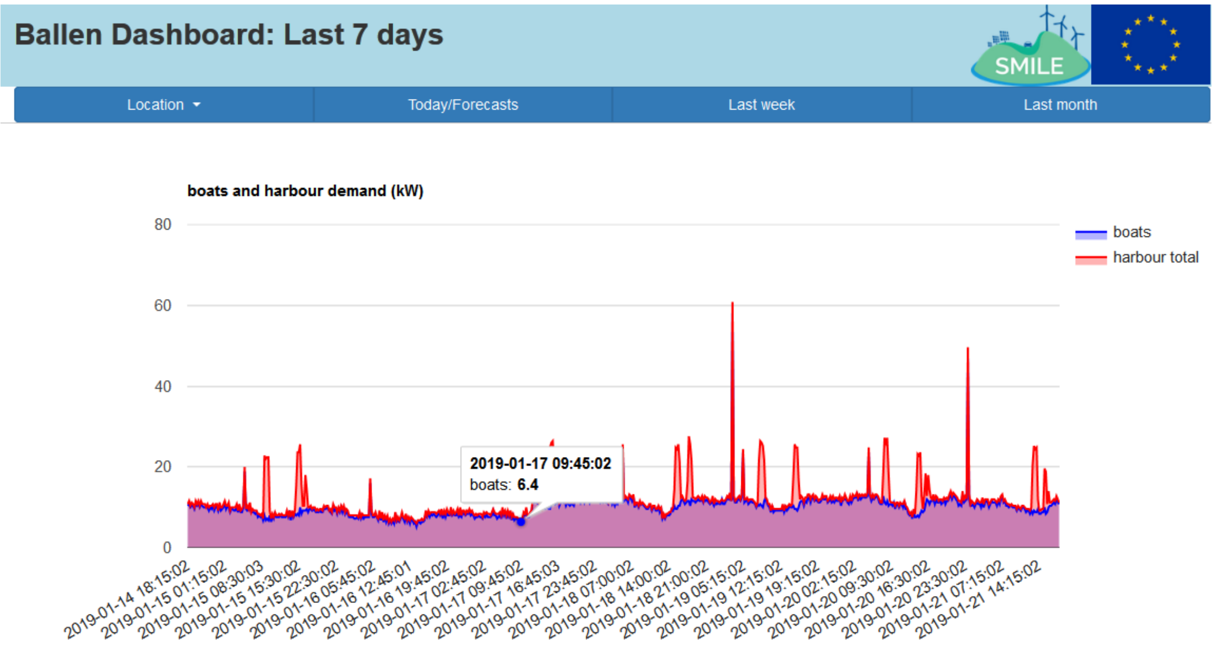


Figure 9. SMILE dashboard. The sauna shows as medium sized peaks (15 kW).

6.2 Electric vehicle charger on the harbour master’s office

The harbour master and his staff use an electric car, and the harbour master’s office has a wall charger, Figure 10. The Samsø Municipality owns the car, which is a Renault ZOE.

The charging power is max 11 kW. The usage pattern is irregular, but it is never used during the night.

Figure 10. Charging point for the marina staff’s electric car.

6.3 Circulator pump in the service building

The service building has floor heating; warm water circulates in pipes under the floors to heat the rooms. A circulator pump drives the circulation (Grundfos Alpha2, max 50 W). The building is connected to the district heating network emanating from the Ballen-Brundby district heating plant, which is 2 km away.

The circulator pump controls the heating of the rooms, and it could be used to dry the building if there is excess renewable electricity. In pseudocode, a rule could be,

```
IF (PV production > demand) and (battery is high) THEN start circulator pump 14:00 – 16:00
```

The room temperature is relatively slow to react, and the floor heating could be switched off during the night. In pseudocode, a rule could be,

```
IF battery is low THEN stop circulator pump 23:00 – 04:00
```

A similar rule could simply stop the circulator pump whenever there is insufficient renewable energy.

6.4 Wastewater tank and pumps

Water from the showers and toilets in the service building flows to an underground tank. Internal pumps send the wastewater to a collector tank at the end of the pier. The wastewater then flows to the Ballen purification plant, independently of the marina system.

The tank and pump system can act as a flexible load. Wastewater is stored in the tank, and the pump can be operated on a favourable schedule. For example, the pump could be run during the night to help discharge the battery before sunrise, so that it is ready to store a new day’s solar energy. In pseudocode, a rule could be,

```
IF battery is not low THEN start wastewater pump at 02:00
```

An internal controller will stop the pump when the tank is empty. The volume of the tank 4.5 cubic metres. There are two high-pressure pumps in the tank (Flygt grinder pump 3069). The pumps are submersible, and they are designed for wastewater containing solids that need to be macerated. The pumps are equipped with grinder devices.

7 The price of electricity

The total electricity demand of the marina is about 100 000 kWh per year, but the PV plant produces only about half of that. Therefore, the marina must buy supplementary electricity from the public grid.

The Ballen marina may buy electricity from an electricity broker at a fixed price for the duration of a contract period, say, three years. Alternatively, the Ballen marina may choose to buy electricity by-the-hour, at a price which follows the spot price on the Nord Pool market. The hourly spot prices are known one day ahead. The raw buying price will be somewhat higher (maybe 15 percent), but taxes and fees increase the final buying price significantly.

Figure 11 shows the variation of the hourly spot price on a random Monday in March (3). There is an increase in the morning from 5 to 8 o'clock and an increase in the evening from 5 o'clock to midnight. The price is 30 – 50% higher during the peak periods compared to mid-day. Oppositely, the price is up to 30% lower during the night (average 32.4 EUR/MWh, standard deviation 7.2 EUR/MWh).

If that pattern is stable, the battery could prevent buying electricity during the expensive peak periods. Furthermore, in case of a cloudy weather forecast, the battery could be filled from the grid during the night instead of buying electricity during the day. In pseudocode, a rule could be,

```
IF (weather forecast is cloudy) and (battery is low) THEN buy from the grid 00:01 to 04:00
```

Rules may conflict with one another, so a *conflict resolution* strategy may be necessary.

Figure 12 shows a cash flow analysis of the project account, assuming a cautious buying price at 0.21 EUR/kWh, including fees and taxes, and a cautious selling price at 0.027 EUR/kWh. The calculation uses the actual price of the PV panels, which turned out less expensive than expected in the previous deliverable D3.1. The municipal investment is paid back after four years according to the cash flow analysis. It is thus a safe investment, which provides a profit for further investments on the marina (more connection points, more power, new payment system).

The cash flow analysis shows that in the course of 25 years the project's *levelized cost of electricity* is 0.16 EUR/kWh. Without the project, the cost would be 0.22 EUR/kWh. The project thus saves 27% on the direct cost of electricity.

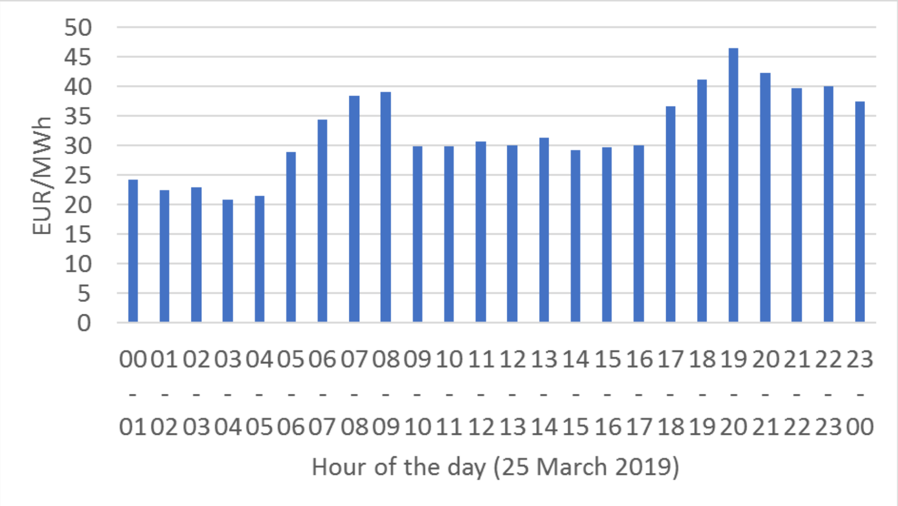


Figure 11. Hourly electricity prices on the spot market (Nord Pool).

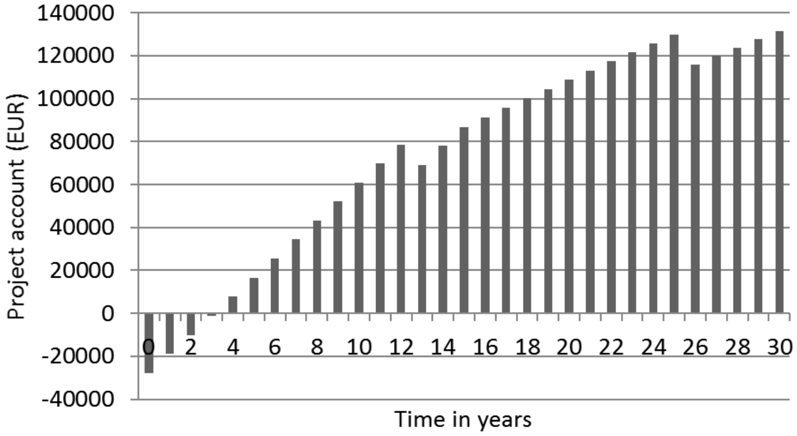


Figure 12. Cash flow analysis of the investment in PV panels.

8 Summary and conclusions

The smart energy system in the Ballen marina consists of two sides: The supply side, and the demand side. The supply side consists of the PV plant, the battery, and the public grid. The solar power fluctuates with the solar irradiation, but the battery stores the renewable energy up to 24 hours. The demand side consists of the boats, the components mentioned in this report, and the remaining electricity consumption in the buildings. Some demand can be delayed, or controlled, to balance the renewable energy generation. Specific loads, such as the heat pumps, link the electricity generation with heating, and the system is thus a smart *energy* system (not just smart *grid*).

Table 3 summarizes the main data. The table shows the inventory of flexible components for a smart energy system. The numbers are essential for simulations. For example, a scheduler based on linear programming must allow for all constraints in terms of max storages and max flows. For simulations, further time series are required as input data; at least on an hourly basis:

- EV charging pattern
- Outdoor temperature pattern
- Heat usage pattern, including hot water (depends on outdoor temperature)
- PV production pattern
- Sauna usage pattern (weekends, week days, holidays, winter, summer)
- Water usage pattern (depends on sauna usage, boat visitors)
- Electricity usage pattern
- Spot prices from Nord Pool

The marina's photovoltaic panels (60 kWp) were installed in March 2019. The inverter on the battery can receive full PV power, and the battery is charged in four full-power hours. Conversely, the battery is discharged in four full-load hours. These are worst case numbers, and the charge/discharge times will be longer — in general the battery will operate on a 24-hour cycle.

The following pseudocode shows the simplest possible strategy for controlling the battery.

```
IF PV power ≥ demand THEN
    IF battery is not full THEN charge battery ELSE sell to grid;
ELSE
    IF battery is not empty THEN discharge battery ELSE buy from grid.
```

Selling to the grid is to be avoided, because the price is low, and it is better to use the solar energy to maximize the self-supply. Buying from the grid is unavoidable, because the PV production is too small to cover the annual demand.

Therefore, the marina must buy electricity from the grid sometimes, and that will be expensive. However, the price may be lower during the night, so the previous strategy should be enhanced, if possible, so that the system prefers to buy during the night.

Another enhancement is to charge the battery aiming at full storage by, say, five o'clock in the afternoon. That is when most boats arrive, and the grid electricity becomes expensive as well. The consumers then use a mixture of PV power and battery power until sunset, where the PV panels end their production. The aim is then to discharge the battery, such that it is empty by the following sunrise.

The overall strategy will be further enhanced by 24-hour forecasts of the supply and the demand.

Table 3. Summary of main data for simulations.

Component	Specification
Marina power injection to grid	Max 49 kW
Marina energy consumption	100 000 kWh/yr
PV simulated energy generation	56 000 kWh/yr
PV actual power	Max 49 kW
PV nominal size	60 kWp
BESS accessible storage	192 kWh
BESS nominal capacity	240 kWh
BESS power	Max 49 kW, in and out
Boat connection points	340 sockets
Heat pump in harbour master’s office	Max 2.6 kW heating power input, max 2.5 kW cooling power input, SCOP 4.56
Heat pump in the Warehouse building	Max 2.6 kW heating power input, max 2.5 kW cooling power input, SCOP 4.56
Heat pumps in the service building	3 x max 2.87 kW heating power input, 3 x max 2.45 cooling power input, heating SCOP 3.97, cooling SEER 5.47
District heating consumption in the service building	18 000 kWh/yr
Wastewater tank storage	4.5 m^3
Wastewater pump speed	Unknown litres/min
Water consumption in the service building	Unknown m^3/yr
Sauna in the service building	15 kW
Electric vehicle charger	11 kW
Buying price of electricity in cash flow analysis	0.21 EUR/kWh
Selling price of electricity in cash flow analysis	0.027 EUR/kWh

9 References

1. SMILE Description of Actions - European Commission. Grant Agreement: Number 731249 SMILE. 2017.
2. Jantzen J, Bak-Jensen B. Specifications and Data Report for the Samsø Demonstrator: Deliverable D3.1 [Internet]. SMILE; 2017. Available from: https://www.h2020smile.eu
3. Day-ahead prices [Internet]. Nord Pool AS. [cited 2019 Mar 29]. Available from: https://www.nordpoolgroup.com/Market-data1/Dayahead/Area-Prices/ALL1/Hourly/?view=table
4. Tilbud Cabin flex model Samsø EI60 (Tender for Cabin flex model Samsø EI60). Energy Cool, Fredericia, Denmark, tender; 2018.
5. Technical specifications of the Samso Battery Energy Storage System. Lithium Balance A/S, Denmark, personal communication; 2018.
6. ABB. Energy Storage Inverter ESI-S: Installation, operation and maintenance instructions. ABB, Belgium, Instruction manual 2GCS236012A0070 – Rev B December 2017; 2017.
7. Tender 1025 Ballen Havn. Better Energy Solutions, Sonderborg, Denmark; 2019.
8. Daikin. Floor standing cased [Internet]. Daikin Europe, UKEPLEN16-1019 / 09.16 / DesignHQ; 2017. Available from: https://my.daikin.eu
9. Daikin. 3MXS-G [Internet]. Excel. [cited 2019 Mar 30]. Available from: https://www.daikin.eu/content/internet-denv/en_US/products/3MXS-G.idownload.xls
10. Daikin. Technical data: Multi model application MXS-G. Daikin Europe, EEDEN15-100; 2015.
11. CompuSoft. Tilbud på nye elstandere + udstyr til trådløs el-måling (Tender for new socket stands + equipment for wireless power metering). CompuSoft, Søndersø, Denmark, tender; 2018.
12. SAWO. Savonia Heater [Internet]. SAWO, Finland, manual SAV_ML_3P_FiEn1117; Available from: https://www.sawo.com/
13. Xylem. Tilbud Scanpipe Ø800 (Tender Scanpipe Ø800). Xylem Water Solutions Denmark ApS, Glostrup, Denmark, tender; 2018.
14. Xylem. Flygt 3069 50 Hz. Xylem Water Solutions Global Services, Emmaboda, Sweden, manual 885872_4.0_en-US_2018-06_TS_Flygt 3069; 2015.

APPENDIX A – *Specifications of the battery cabin*

Source: Energy Cool (4)

Component	Specification
Model	Cabin flex model Samsø EI60
Internal measures W x L x H	240 x 320 x 240 cm
External measures W x L x H	262 x 342 x 280 cm
Foundation with holes for lifting	Galvanized steel
Walls, floor and ceiling hard pressed rock wool	100 mm, fire reaction A2-S1d0, EI 60
Fire door in galvanized surface	EI 60
Exterior colour	RAL 3009 Oxide red (Swedish red)
Internal colour	RAL 9002
Floor surface	Vinyl
Drain in floor	Exterior closing mechanism
Roof surface	Roofing felt with 2 degrees slope
Equipment for free cooling, low energy, sea filter	290 kWh per year
Partitioned cable trenches in the ceiling	3 lanes
Reinforced console on wall for the inverter	
LED lighting	230 V AC
Sprinkler in the ceiling, outside hose connector	Storz C 2 inches
Price including delivery on marina, ex tax (VAT)	192 200 DKK (25 600 EUR)
Supplier	Energy Cool, Fredericia, Denmark

APPENDIX B – *Specifications of the battery energy storage system*

Source: Lithium Balance (5)

Item	**Specification**	
Dimensions of single rack	600x600x2000mm	
Chemistry cathode	NMC	
Chemistry anode	Graphite	
Number of battery racks	3	
Number of battery packs per battery rack	8	
Power	50kW	
Energy	240kWh	
Battery voltage	585 – 806V (DC)	
Expected life	15 years	
Nominal network AC side voltage	400 V (AC)	
Inverter type	3 phase (3W and 4W)	
Selected features:	• Modularity (easy expandability) • Auxiliary power consumption saving mode • Dynamic power control (P) and reactive power control (Q) • Individual power control • Harmonic mitigation up to 50th • Load balancing • Islanding mode • Black start (as an option) LVRT (Low Voltage Ride Through)	

APPENDIX C – *Specifications of the energy storage inverter*

Source: ABB (6)

Item	Specification
Recommended maximum average temperature (over 24 h)	35°C
Degree of protection	IP30
Dimensions per power unit enclosure (appr.)	W x D x H: 588 x 326 x 795 mm (including fixations)
Weight per power unit enclosure (unpacked)	130 kg
Power rating at 400 Vac	Unit type 4: 50 kW
Equipment losses	3% of the equipment rated power typically
Load balancing	Off Phase to phase, phase to neutral (if neutral present), both (if neutral present)
Communication	Through ESI-Manager display. Through Modbus RTU (with optional RS485 Modbus Adapter). Through Modbus TCP (with Ethernet). Through dedicated optional software PQF-link (with USB Ethernet)
Programming	Through ESI-Manager display. Through USB-Ethernet with dedicated optional software (PQF-Link).

APPENDIX D – *Specifications of the marina site PV panels*

Source: Better Energy (7)

Marina site	Item	Specification
Marina total	Nominal power	37.49 kWp
	Generator surface	193.6 m2
	PV modules	119
	Inverters	2
	Yield (AC side)	37 860 kWh
	Specific annual yield	1010 kWh/kWp
	Investment	56 227 DKK (7500 EUR)
Building 03 – roof area South East	PV modules	Eurener 49 x TURBO_315
	Slope	20 deg
	Orientation	South east 155 deg
	Generator surface	79.7 m2
	Inverter	Fronius Symo 12.5-3-M
	Dimensioning factor	123.5 %
Building 01 – roof area South East	PV modules	Eurener 52 x TURBO_315
	Slope	45 deg
	Orientation	South east 150 deg
	Generator surface	84.6 m2
Building 04 – roof area North East	PV modules	Eurener 18 x TURBO_315
	Slope	8 deg
	Orientation	North east 60 deg
	Generator surface	29.3 m2
	Inverter for Building 01 (South East) and Building 04 (North East)	Fronius Symo 20.0-3-M
	Dimensioning factor	110.2 %
	Phases	3 x 230 V
	Cos phi	+/- 1
Simulation results	Generator power	37.5 kWp
	Specific annual yield	1010 kWh/kWp
	Efficiency (PR)	86.4 %
	Degradation due to shade	1.7 % per year
	Production to grid	37 860 kWh per year
	Stand-by consumption (inverter)	26 kWh per year
	CO2 reduction	22 714 kg per year

APPENDIX E – *Specifications of the harbour master office PV panels*

Source: Better Energy (7)

Harbour master's office	Item	Specification
Total	Nominal power	3.78 kWp
	Generator surface	19.5 m2
	PV modules	12
	Inverters	12
	Yield (AC side)	3550 kWh per year
	Specific annual yield	940 kWh/kWp
	Investment	5670 DKK (756 EUR)
Building 01 – roof area West	PV modules	Eurener 6 x TURBO_315
	Slope	6 deg
	Orientation	West 270 deg
	Generator surface	9.8 m2
	Inverters	6 x Enphase Energy M250-60-230-S22/S25
	Dimensioning factor	126 %
Building 01 – roof area East	PV modules	Eurener 6 x TURBO_315
	Slope	6 deg
	Orientation	East 90 deg
	Generator surface	9.8 m2
	Inverters	6 x Enphase Energy M250-60-230-S22/S25
	Dimensioning factor	126 %
Simulation results	Generator power	3.8 kWp
	Specific annual yield	940 kWh/kWp
	Efficiency (PR)	88.7 %
	Degradation due to shade	0 % per year
	Production to grid	3550 kWh per year
	Stand-by consumption (inverter)	3 kWh per year
	CO2 reduction	2132 kg per year

APPENDIX F – *Specifications of the fence site PV panels*

Source: Better Energy (7)

Fence site	Item	Specification
Fence total	Nominal power	18.9 kWp
	Generator surface	97.6 m2
	PV modules	60
	Inverters	1
	Yield (AC side)	14 850 kWh
	Specific annual yield	786 kWh/kWp
	Investment	28 400 DKK (3790 EUR)
Fence	PV modules	Eurener 60 x TURBO_315
	Slope	90 deg
	Orientation	South east 150 deg
	Generator surface	97.6 m2
	Inverter	Fronius Symo 15.0-3-M
	Dimensioning factor	126 %
Simulation results	Generator power	18.9 kWp
	Specific annual yield	786 kWh/kWp
	Efficiency (PR)	89 %
	Production to grid	14 850 kWh per year
	Stand-by consumption (inverter)	14 kWh per year
	CO2 reduction	8910 kg per year

APPENDIX G – *Specifications of the heat pump in the harbour master's office*

Source: Heat pump outdoor unit nameplate

Item	Specification
Heat pump outdoor unit	
Manufacturer	Daikin Industries Czech Republic s.r.o
Model	RXS25L3V1B
Serial number – YYYY/MM	J038727 – 2016/07
Power supply	220-240 V ~ 50 Hz
Protection	IPX4
Refrigerant	R410A / 1.0 kg
Net weight	34 kg
Fuse amp	16 A
PS HIGH/LOW	4.17/2.75 MPa
Rated current (max)	14 A
GWP tCO2eq	2087.5 / 2.09

Source: Daikin (8)

Item	Specification
Heatpump indoor unit	
Manufacturer	Daikin Industries Czech Republic s.r.o
Model	FVXS25FV1B
Nominal cooling capacity	2.5 kW
Nominal heating capacity	3.4 kW
Pdesign heating	2.6 kW
Pdesign cooling	2.5 kW
Seasonal efficiency heating (SCOP)	4.56
Seasonal efficiency energy label	A+
Accessories	Modbus gateway, wifi adapter, wired adapters

APPENDIX H – *Specifications of the heat pump in the service building*

Source: Daikin (9) and nameplate

Item	Specification
Manufacturer	Daikin Industries Czech Republic s.r.o
Outdoor unit	
Model	3MXS68G3V1B2
Compressor output	1380 W
Fan power consumption standard	48 W
Serial number – YYYY/MM	J044152 – 2018/10
Power supply	220-240 V ~ 50 Hz
Protection	IPX4
Refrigerant	R410A / 2.59 kg
Net weight	54 kg
Fuse amp	20 A
PS HIGH/LOW	4.17/2.75 MPa
Rated current (max)	18.1 A
GWP tCO2eq	2087.5 / 5.41

Source: Daikin (10)

Item	Specification
Manufacturer	Daikin Industries Czech Republic s.r.o
3 indoor units, model	25
Heating capacity	3x2.86 kW
Heating power input	3xMax 2.87 kW
Heating SCOP	3.97
Heating Energy label	3xA
Cooling capacity	3x2.26 kW
Cooling power input	3xMax 2.45 kW
Cooling SEER	5.47
Cooling energy label	3xA

APPENDIX I – *Specifications of the connection points for the boats*

Source: CompuSoft (11)

Item	Specification
26 socket stands	CompuSoft A/S
Model	Seijsener
Main isolator	63A 4pins
6 sockets	CEE 3 pins 230V 16A
1 socket	CEE 5 pins 400V 16A
Light cap	7W
6 kWh meters	Modbus DIN 1 pin
1 kWh meter	Modbus 3 pins
6 contactors	2 pins NO+NC 20A
1 contactor	4 pins 4xNO
1 antenna	PUK XBee
1 communication module	CompuMat 7 channels XB7 Modbus module
1 DC power supply	24 VDC DIN 30W

Item	Specification
2 socket stands	CompuSoft A/S
Model	Seijsener
Main isolator	63A 4pins
6 sockets	CEE 3 pins 230V 16A
1 socket	CEE 5 pins 400V 32A
Light cap	7W
6 kWh meters	Modbus DIN 1 pin
1 kWh meter	Modbus 3 pins
6 contactors	2 pins NO+NC 20A
1 contactor	4 pins 4xNO
1 antenna	PUK XBee
1 communication module	CompuMat 7 channels XB7 Modbus module
1 DC power supply	24 VDC DIN 30W

Item	Specification
1 socket stand	CompuSoft A/S
Model	Seijsener
Main isolator	63A 4pins
5 sockets	CEE 3 pins 230V 16A
1 socket	CEE 5 pins 400V 16A
Light cap	7W
6 kWh meters	Modbus DIN 1 pin
1 kWh meter	Modbus 3 pins
6 contactors	2 pins NO+NC 20A
1 contactor	4 pins 4xNO
1 antenna	PUK XBee
1 communication module	CompuMat 7 channels XB7 Modbus module
1 DC power supply	24 VDC DIN 30W

Item	Specification
20 retrofit socket stands	CompuSoft A/S
112 sockets total	1 phase 16A
31 sockets total	3 phases 16A
112 kWh meters total	Modbus DIN 1 pin
31 kWh meters total	Modbus 3 pins
112 contactors total	2 pins NO+NC 20A
31 contactors total	4 pins 4xNO
12 antennas total	PUK XBee
20 communication modules total	CompuMat 7 channels XB7 Modbus module
20 DC power supplies total	24 VDC DIN 30W
20 light caps	7W

APPENDIX J – *Specifications of the sauna in the service building*

Source: SAWO (12)

Item	Specification
Manufacturer	Sawo Inc.
Model	Savonia sauna heater SAV-150N
Supply voltage	400V 3N~
Max power	15 kW
Heating elements	6 x 1.5 kW, 3 x 2.0 kW
Stones	60-75 kg
Fuse	3 x 16 amp

APPENDIX K – *Specifications of the wastewater tank and pumps*

Source: Xylem (13)

Item	Specification
Tank	Ø800 polyethylene (PE)
Supplier	Xylem
Manufacturer	Scanpipe
Outer dimensions	Cylinder diameter 800 mm, length 2500 mm
Wall thickness	20 mm
Mounting	Vertical underground
Outlet pipe	Diameter 50 mm

Source: Xylem (14)

Item	Specification
Pump	Grinder pump
Supplier	Xylem
Manufacturer	Flygt
Model	MP 3069-254 HT
Pressure class	HT – high head
Installation type	P semipermanent
Rated power	1.7 kW
Supply voltage	3x400V~ 50Hz
Number of starts per hour	Maximum 15
Accessories	Electrical accessories such as pump controller, control panels, starters, monitoring relays, cables
Impeller no	254
Revolutions per minute	2700 rpm
Rated current	3.8 A
Start current	17 A
Cos phi	0.87
Performance at 5 m head	4.5 litres per second (P2 = 1.5 kW)