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ELECTRICITY DEMAND FOR OFF-GRID ISLAND GROUPS

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Abstract

This report present result from a survey investigating the electricity consumption for four different off-grid island groups in the Kvarken archipelago, off the coast of Vasa. Obtained results have been used to estimate the size of needed battery banks, and advice is provided for how to keep the electricity demand at a minimum, as this affects investment costs.

Sammanfattning

Denna rapport presenterar resultat från en undersökning angående el-energibehovet vid fyra off-grid ögrupper i Kvarkens skärgård utanför Vasas kust. Resultaten har använts för att uppskatta storleken på en batteribank som kunde förse ögruppen med el-energi. Utöver så presenteras även råd för hur el-energibehovet kan minskas, då detta påverkar investeringskostnaden för off-grid lösningar.

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Contents

1 Introduction

REMOTE islands located in the archipelago most often lack a fixed connection to the electrical grid. Nature stations, communication services, and similar buildings located on these islands are therefore in need of off-grid energy solutions to accommodate their needs. In order to dimension the energy solution correctly, it is necessary to have an estimation of the demand. Here, the estimated electrical demand for four island groups in the Kvarken archipelago is presented separately. Additionally, advice is given on how to reduce energy usage, and hence, keep down installation and maintenance costs for off-grid solutions.

The work was conducted within the project **Pisara meressä** (English translation: A drop in the sea). This was a 3 year project set out to investigate and develop small-scale decentralized solutions for integrating automated renewable energy sources in a sustainable manner. The investigation was divided into different areas regarding production, distribution, and usage of the renewable energy sources, including the profitability aspect of the implemented solutions. Funding was received from the Centre for Economic Development, Transport, and the Environment, and the European Agricultural Fund for Rural Development. The project was run by the *Vaasa Energy Institute* (VEI) and the University of Jyväskylä in cooperation with the Metsähallitus unit in Vasa. VEI is a cooperative organisation founded by the University of Vaasa, the Levón Institute, Novia University of Applied Sciences, and Vaasa University of Applied Sciences, with a long term goal to increase local know-how within energy related fields (Vaasa Energy Institute, n.d.; Levón-instituutti, 2012).

2 Investigated islands

THE island groups investigated are all found in the Kvarken Archipelago (see Figure 1), off the coast of Vaasa. The island names (in Swedish) together with abbreviations that will be used throughout this report are:

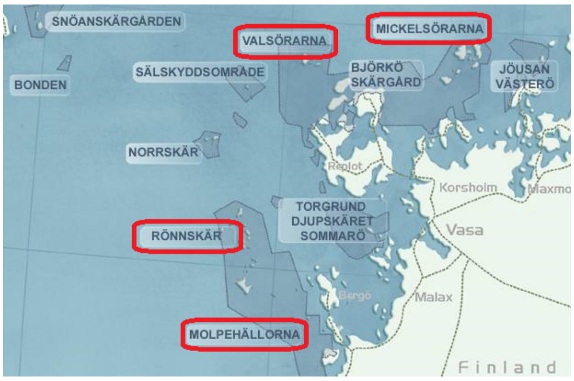

Figure 1: The Kvarken archipelago, image adapted from (Kvarkenrådet, n.d.).

- Mickelsörarna (MIC)
- Molpehällorna (MOL)
- Rönnskären (RON)
- Valsörarna (VAL)

None of the island groups are connected to the grid, but they all have buildings that are to be maintained in order to prevent them from deteriorating. These buildings serve different purposes, such as radar services, cafés, and nature stations. For the above reasons, sustainable energy solutions are needed in order to maintain the activities.

A few of the island groups are already equipped with some kind of energy systems, such as wind turbines, solar panels, and diesel generators. These systems are presented below together with a more general overview of each island groups. At the end of the report, a summary with more detailed information is also presented in Table A-1 (Appendix A).

2.1 Mickelsörarna

Mickelsörarna represents a group consisting of nearly 300 islands. The main building is located at the highest point on an island called Kummelskäret, and it consist of two floors, a tower for coastal guarding, and a basement. The building that can be seen

Figure 2: Mickelsörarna (Hallantie, n.d.).

Figure 3: Molpehällorna (Hallantie, n.d.).

in Figure 2 was constructed in 1987 to be a coastguard station, but nowadays it is owned by the Finnish forest administration (Metsähallitus) and it is only used as a nature station and café for tourists in the summer. At present, the electrical energy is obtained from two Diesel Generators (Ford 2525E 75 kW and Ford 2526E 50 kW), a wind turbine (3 kW), and solar panels (3.8 kW tot.), and the energy is stored in a battery bank (48 VDC, 1500 Ah). Heating is accomplished with both an oil-fired water (glycol) heater (Riello 3062 428TI) and heat exchangers (collecting heat from the diesel generators exhaust gases) (Puig et al., 2012).

2.2 Molpehällorna

Molpehällorna is a 2 km long island that was formed from four separate islands which merged to a single island due to post-glacial rebound. The southern part of the island is called Söderhällorna, and it holds a closed down coastguard station that nowadays serves as a nature station. The station, shown in Figure 3, was built in the 70's and is nowadays owned by Metsähallitus. Currently the energy solution consists of a battery bank (24 VDC, 440 Ah), one diesel generator, one oil fired water heater, and eight solar panels (0.96 kW tot.) (Puig et al., 2012).

2.3 Rönnskär

Rönnskär, located 40 km to the west of Vasa, is an island group consisting of hundreds of small islands, among which Faliskäret (see Figure 4) is the most important one. Most buildings found on the islands are summer cottages, but Fallskäret also holds an old pilot station that now serves a nature station. All islands are owned by Metsähallitus, and taken together, the energy solution consists of 12 solar panels (1.2 kW tot.) along with a battery bank (48 VDC, 400 Ah) (Puig et al., 2012).

2.4 Valsörarna

Valsörarna, also a group of islands, are located about 45 km north-west of Vasa. The main island, named Storskär, holds a lighthouse, and one of the smaller islands also holds a former coastguard station (owned by the Finnish State properties) and a biological station for bird observations (owned by Ostrobothnia Australis). The former coastguard station, shown in Figure 5, is the main object on Valsörarna and currently there is no sustainable energy solution for this building. However, for other purposes the islands already have a small system consisting of a

Figure 4: Rönnskär (Hallantie, n.d.).

Figure 5: Valsörarna (Hallantie, n.d.).

140 W, 12 V solar panel and a 12 V, 220 Ah battery (Puig et al., 2012; Valsörarna, 2009; Kvarkenrådet, n.d.).

3 Electricity demand

The *Energy Evaluation Model* (EEM), developed in Puig et al. (2012), can estimate the energy demand (electricity and heat) for any building. It was previously applied to Mickelsörarna and Valsörarna, and the obtained results were investigated and improved upon in this section. Also, new calculations have been run to define the energy demand of the remaining locations, i.e. Rönnskäret and Molpehällorna.

The results from the EEM were here improved with more exact electricity demand calculations based upon used electrical appliances and their usage pattern. A summary of the results is given in Table 1, showing both electric power and energy. The demand varies strongly between seasons and calculations were performed separately for both the summer season (3 months) and the winter season (9 months). Spring and fall have been included in the winter season since the demand during these periods is the same as during the winter. Furthermore, only alternate current appliances (230 VAC) were included in the calculations. So, it was assumed that an inverter is always used between the appliances ant the battery bank.

The peak power in Table 1 is the demand when all appliances are running. This is the largest demand that the system must be able to handle, and it is calculated as:

$$P_{\text{peak}} = \sum_{i=1}^{n} \frac{P_i}{\eta_{\text{inv}}} \tag{1}$$

where n is the number of appliances, P_i is the rated power for a certain appliance, and η_{inv} is the efficiency factor of the inverter. The average power in turn is calculated using:

$$P_{\text{avg}} = \sum_{i=1}^{n} \frac{P_i h_i d_i m_i}{h_{\text{season}} \eta_{\text{inv}}} \tag{2}$$

where h_i is the number of hours the appliance is running per day, d_i the number of days the appliance is running per month, and m_i the number of months the appliance is running per season. The total number of hours per season is defined as h_{season} and it is calculated as:

$$h_{\text{season}} = 24 \frac{\text{h}}{\text{day}} 30.42 \frac{\text{day}}{\text{month}} m_s \frac{\text{month}}{\text{season}} \tag{3}$$

where one month consists of 30.42 days (365/12), and m_s is defined as 3 months for the summer season and 9 months for the winter season. The energy consumptions (day, month, season) in Table 1 are further determined as:

$$E_t = P_{\text{avg}} t \tag{4}$$

where t is the amount of hours for the respective time lapse, 24 hours in a day, 730 hours in a month, 2190.24 hours in the summer season, 6571 hours in the winter season, and 8760 hours in a year. The total energy consumption per year is finally determined as:

$$E_{\text{year}} = E_{\text{winter}} + E_{\text{summer}} \tag{5}$$

Table 1: Summary of electricity consumption

	Power [kW]		**Energy** [kWh]			
	Avg.	Peak	Day	Month	Season	Year
MIC / VAL						
Summer	1.3	10.9	31	934	2802	**3532**
Winter	0.1	0.1	3	81	729	
MOL						
Summer	0.3	4.3	8	250	751	**751**
Winter	0.0	0.0	0	0	0	
RON						
Summer	0.3	1.9	7	206	620	**620**
Winter	0.0	0.0	0	0	0	

The electricity demand calculations are also dependent on the number of visitors per season. During the summer of 2011, Mickelsörarna accommodated 100–150 visitors, but this is less than the average from previous years (J. Carlsson, personal communication, 2012). However, no exact information regarding previous years is available. So, it was decided that the electricity demand calculations should take into account the maximum possible number of visits per season, which is 800 over-night visits per year (K. Hallantie, personal communication, 2012). This number was divided into groups with 20 visitors each, resulting in 40 groups per season each staying one night. This number (40 groups with 20 visitors each) applies to Mickelsörarna, but it was also used for electricity demand calculations on Molpehällorna, Rönnskären, and Valsörarna in order to obtain the highest possible peak electricity demand.

The EEM in Puig et al. (2012) includes a model for estimating the battery bank size based upon a calculated average electricity demand. This model has here been applied to all island groups, and the results are shown in Table 2. More specifically, the model estimates the size of the battery bank as:

$$Q = \frac{P_{\text{avg}} t_Q}{U_{\text{batt}} q} \tag{6}$$

where Q is the needed battery bank capacity (Ah), t_Q the wanted running time in hours for a fully charged battery bank, U_{batt} the nominal voltage of the battery system, and q the maximum discharge percentage for the battery system.

A complete list of all appliances and their corresponding power, quantity, and usage time can be found in accompanying appendices.

- Mickelsörarna and Valsörarna - Appendix B
- Molpehällorna - Appendix C
- Rönnskären - Appendix D

Mickelsörarna

Taking into account both the café and the nature station, average and peak power for the summer season was determined to be 1.3 kW and 10.9 kW respectively. Assuming a battery bank with a capacity for one week, this resulted in a battery bank size of 4.5

Table 2: Summary of estimated battery systems

Location	Hours of backup	Voltage	Inverter efficiency	Max discharge	Capacity [Ah]
MIC / (VAL)	168	48	90 %	80 %	**4535**
MOL	168	24	90 %	80 %	**2430**
RON	168	48	90 %	80 %	**1002**

kAh which is roughly three times more than the existing capacity of 1.5 kAh.

The appliances with the highest energy consumption are found in the café, where both the refrigerators and freezers are located. The coffee maker also consumes a lot of electricity, but usage is already minimized by storing coffee in a thermos (J. Carlsson, personal communication, 2012). Other appliances with a high electricity consumption are the microwave and the vacuum cleaner, but these applications are seldom used.

Molpehällorna

The electricity demand of Molpehällorna consists mostly of refrigerators, lighting and, customer appliances. Peak demand reaches 4.3 kW, whereas the average demand is only 0.3 kW. The suggested battery bank size needed to sustain operations for one week is 2.4 kAh which is quite large relative to the average demand, but this is due to a lower battery voltage (24 VDC) which reduces the amount of energy that can be extracted from the batteries.

Rönnskär

The largest energy consumer on Rönnskär is the refrigerator. Together with other appliances, peak demand here reaches 1.9 kW and the average demand was calculated to be 0.3 kW. This leads to a suggested battery bank size of 1 kAh in order to sustain operations for one week.

Valsörarna

Valsörarna holds no activity during the seasons and since it also lacks an energy solution the consumption is currently zero. However, Valsörarna could be a possible location for future accommodation and restaurant activity, and in such a case, the consumption would be very similar to the one on Mickelsörarna (K. Hallantie, personal communication, 2012). For this reason the reported values are identical to the ones reported for Mickelsörarna.

4 Reduced demand

For off-grid electricity system, it is essential to reduce the electricity demand as much as possible. Each kWh saved is one less that have to be produced and maybe also stored. Hence, lowering the consumption also lowers both the needed production capacity and the needed storage capacity. In the end, this also leads to lowered installation costs.

There are several things that the consumer can do to reduce the electricity consumption, and a few tips are:

- Use *compact fluorescent lights* (CFL) instead of incandescent light bulbs.
- Turn off the lights if you leave the room for a longer time.
- Always turn off or unplug devices that are running on stand-by, e.g. TVs or computers.
- Turn up the temperature in refrigerators and fridges a couple of degrees.
- Never put warm food in a refrigerator.

- Keep the area around/behind the refrigerator as free as possible.
- Do not cook (heat water, make coffee) or heat/cool the building with electricity.
- Use electricity wisely, always consider if the appliance is actually necessary to use.

4.1 Running time

The running time of a system can be calculated from the demand and the stored energy available. Here, a hypothetical case is assumed where an off-grid electricity system contains two 24 V 220 Ah batteries, one inverter operating at 90 % efficiency, and ten 60 W incandescent light bulbs. For a fully charged battery bank, the energy stored in this system is determined as:

$$E = nU_{\mathrm{batt}}Q_{\mathrm{batt}}\eta_{\mathrm{inv}} \tag{7}$$

where E is the energy, n is the number of batteries, U_{batt} is the nominal voltage, Q_{batt} is the electric charge stored in the battery bank (in ampere-hours), and η_{inv} is the inverter efficiency. For the presented case this results in 9504 Wh. When using ten 60 W incandescent light bulbs, the total running time is calculated by dividing the available energy (9504 Wh) with the total power demand (600 W), which results in a running time of **15.84 hours**. Performing the same calculations with ten 15 W CFL lights (according to the manufacturer these emit the same amount of light as a 63 W traditional bulb) results in a running time of **63.36** hours. That is, by using CFL lights it is possible to obtain the same amount of light for four times as long. However, these calculations do not take into account that the battery voltage will drop in proportion to the electric charge of the battery, and hence, they are not exact. Still, this example highlights the benefits of using CFL lights instead of incandescent light bulbs.

In order to get a feel for how much energy different appliances use, Table 3 lists a couple of common household appliances together with their power demand and calculated running time in the previously presented example.

5 Conclusions

This report has strived to determine the electricity demand on four different island groups in the Kvarken archipelago. Usage patterns for different appliances have been used as base for estimating both peak and average demand, and the size of a battery bank. In the future, this information could be used when designing new off-grid energy solutions for these island groups.

In all investigated cased, the largest

Table 3: Run-time for different appliances

Appliance	Power [W] (approx.)	Running time* [h] (approx.)
Incandescent light bulb	60	158.4
CFL light bulb	15	633.6
Refrigerator	200	47.5
Coffee Maker	900	10.6
Vacuum Cleaner	1500	6.3
Heater with fan	3000	3.2
Heater with fan	6000	1.6

*calculated with 2 pcs. 24V 220 Ah batteries (total 9504 Wh with 90 % eff. inverter) energy consumers where refrigerators and freezers, and these therefore determine to a great extent what the total demand will be. Hence, these also affect installation costs significantly. A lower demand means that less energy will have to be produced and stored. In order to illustrate the effect, it was shown that CFL lights can produce the same amount of light as incandescent light bulbs but for four times as long.

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A Island summaries

Table A-1: Summary over installed systems and existing buildings

Properties	Island MIC	MOL	RON	VAL
Building size				
Gross floor area [m^2]	689	338	238	689
Volume [m^3]	1994	1019	780	N/A
Energy production				
Electricity				
Solar cells [pcs]	16	8	12	1
Solar cells tot. power [kW]	3.8	0.96	1.2	140
Wind Mills [pcs]	1	-	-	-
Wind Mills tot. power [kW]	3.2	-	-	-
Diesel generators [pcs]	2	1	-	2
Diesel gen. tot power [kW]	125	N/A	-	N/A
Inverters [pcs]	3	1	N/A	-
Inverters tot. power [kW]	6.9	3.5	N/A	-
Heat				
Oil fired water heater [pcs]	1	1	-	N/A
Oil fired water heater [kW]	2	N/A	-	N/A
Diesel generators [pcs]	2	-	-	2
Diesel generators [kW]	125	-	-	N/A
Energy storage				
Batteries [pcs]	24	4	8	1
Battery voltage [V]	48	24	48	12
Battery capacity tot. [Ah]	1500	440	400	220

N/A = No information available

B MIC (VAL) - Alternating current appliances

ALTERNATE CURRENT (AC)			SUMMER: 3 months						WINTER: 9 months						
Appliance Name	Power (W)	Quantity Summer	Total (W)	h/day	days/month	months/season	Wh/day when in use	AVG Load by season, including inverter @ 90 % efficiency	Quantity Winter	Total (W)	h/day	days/month	months/season	Wh/day when in use	AVG Load by season, including inverter @ 90 % efficiency
OBS. TOWER															
Exit lights	11	1	12,2	24	30	3	264	12,2							
Lighting	36	4	160,0	4	20	2	576	11,7							
2ND FLOOR															
Staircase lighting	36	1	40,0	4	20	2	144	2,9							
Corridor lighting	36	3	120,0	4	20	2	432	8,8							
Room lighting	11	5	61,1	4	30	1	220	3,4							
Tech. Fac.															
Not in use!															
Kitchen															
Refrigerator	200	1	222,2	20	20	2	4000	81,2							
Lighting	36	2	80,0	4	20	2	288	5,8							
Work lighting	36	1	40,0	4	20	2	144	2,9							
Dining room															
Exit lights	11	2	24,4	24	30	3	528	24,4							
Lighting	18	4	80,0	5	20	2	360	7,3							
WC 1	18	1	20,0	2	20	2	36	0,7							
WC 2	29	1	32,2	2	20	2	58	1,2							
Video projector	235	1	261,1	3	5	1	705	1,8							
Laptop	200	2	444,4	4	5	1	1600	4,1							
1ND FLOOR															
Staircase lighting	36	1	40,0	5	20	2	180	3,7							
Staff room light.	11	3	36,7	5	20	2	165	3,3							
Accomodation light	18	6	120,0	5	20	2	540	11,0							
Accom. hair dryer	1300	1	1444,4	1	10	1	1300	6,6							
CAFÉ															
Microwave oven	800	1	888,9	1	1	3	800	1,2							
Coffee maker	750	1	833,3	1	30	3	750	34,7							
Refrigerators	200	3	666,7	20	30	3	12000	555,5							
Freezer	200	3	666,7	12	30	3	7200	333,3							
Radio	20	1	22,2	10	30	3	200	9,3							
Vacuum cleaner	1000	1	1111,1	2	2	3	2000	6,1							
OUTSIDE															
Lighting	60	4	266,7	1	15	1	240	1,8							

Sauna water pump	400	1	444,4	1	20	2	400	8,1							
<u>**BASEMENT**</u>															
Staircase lighting	36	2	80,0	1	15	1	72	0,5							
Basement light.	33	1	36,7	1	15	1	33	0,3							
Workshop light	36	2	80,0	1	15	1	72	0,5							
Storage lighting	11	1	12,2	1	15	1	11	0,1							
Battery room light.	36	1	40,0	1	15	1	36	0,3							
Generator room															
Lighting	22	1	24,4	1	15	1	22	0,2							
Elec. Burner	90	1	100,0	4	15	3	360	8,2							
Burner oil pump	55	1	61,1	4	15	3	220	5,0							
Generator fuel pum	75	1	83,3	1	10	1	75	0,4							
SCADA	100	1	111,1	24	30	3	2400	111,1	1	111	24	30,4	9	2667	111
Well water pump	2000	1	2222,2	1	10	1	2000	10,1							
Circ. water pump	80	1	88,9	7	30	3	560	25,9							
Control equipment	20	1	22,2	24	30	3	480	22,2							
Total AC Consumption			**10990**				**40431**	**1280**		**111**				**2667**	**111**

C MOL - Alternating current appliances

ALTERNATE CURRENT (AC)			SUMMER: 3 months						WINTER: 9 months						
Appliance Name	Power (W)	Quantity Summer	Total (W)	h/day	days/month	months/season	Wh/day when in use	AVG Load by season, including inverter @ 90 % efficiency	Quantity Winter	Total (W)	h/day	days/month	months/season	Wh/day when in use	AVG Load by season, including inverter @ 90 % efficiency
Kitchen / Hall															
Refrigerator	200	1	222,2	20	20	2	4000	81,2							
Refrigerator+Freez	500	1	555,6	20	20	2	10000	202,9							
Lighting	11	5	61,11	5	20	2	275	5,6							
Accomodation															
Accom. lighting	11	15	183,3	5	20	2	825	16,7							
Video Projector	235	1	261,1	2	3	2	470	1,4							
Laptop	200	3	666,7	5	5	2	3000	15,2							
Phone charger	5	5	27,78	5	5	2	125	0,6							
Outdoor															
Lighting	11	3	36,67	3	15	1	99	0,8							
Tech. Fac.							0								
Water pump	2000	1	2222	1	10	1	2000	10,1							
Electric burner	90	1	100	4	15	3	360	8,2							
Total AC Consumption			**4337**				**21154**	**343**		**0**				**0**	**0,00**

D RON - Alternating current appliances

ALTERNATE CURRENT (AC)			SUMMER: 3 months						WINTER: 9 months						
Appliance Name	Power (W)	Quantity Summer	Total (W)	h/day	days/month	months/season	Wh/day when in use	AVG Load by season, including inverter @ 90 % efficiency	Quantity Winter	Total (W)	h/day	days/month	months/season	Wh/day when in use	AVG Load by season, including inverter @ 90 % efficiency
MAIN BUILDING															
Refrigerator	200	3	666,7	20	20	2	12000	243,5							
Lighting	11	5	61,1	4	20	2	220	4,5							
Accomodation															
Accom. lighting	11	15	183,3	5	20	2	825	16,7							
Video Projector	235	1	261,1	2	3	2	470	1,4							
Laptop	200	3	666,7	5	5	2	3000	15,2							
Phone charger	5	5	27,8	5	5	2	125	0,6							
OUTDOOR															
Lighting	11	5	61,1	2	15	1	110	0,8							
Total AC Consumption			**1928**				**16750**	**283**		**0**				**0**	**0,00**

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