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Electricity analysis for energy management in neighbourhoods: Case study of a large housing cooperative in Norway

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Abstract. As a basis for energy management in apartment blocks, this paper characterises electricity use in a Norwegian housing cooperative with 1,058 apartments. In 2018, the average specific electricity delivery to apartments and common areas is 56.7 kWh/m^2 or 2,301 kWh per resident, in addition to heat delivery from district heating. Average annual electricity use in the apartments is 4,362 kWh and average maximum hourly load is 3.2 kWh/h. The electricity coincidence factor is 0.323. The study suggests a potential for shifting electricity loads in time on a neighbourhood level, where especially EV charging can be utilized as a flexible load.

1. Introduction

In zero emission neighbourhoods, thermal and electric energy should be managed in a flexible way, to achieve reduced power peaks, reduced energy use, reduced CO_2-emissions and increased self-consumption of locally produced energy [1], [2]. Further, smart management of building loads can provide energy flexibility services to distribution system operators (DSOs) and district heating companies. As a basis for energy management in apartment blocks, this paper characterises the electricity use in a large housing cooperative in Norway, built in the 1970s.

The Risvollan housing cooperative consists of 1,058 apartments with a total of 93,713 m^2 heated floor area, distributed on 121 similar apartment blocks. There are apartments with one bedroom (52.9 m^2), two bedrooms (83.5 m^2), three bedrooms (104.8 m^2) and four bedrooms (107.2 m^2), where 78% are two- or three-bedroom apartments. In total 2,321 residents live in the apartments, 53% female and 47% male, where 24% are under 20 years old, 40% between 20 and 50 and 33% above 50 years old [3].

Space heating and domestic hot water (DHW) is provided by district heating, which is analysed in a parallel study [4]. A majority of the apartments have electric floor heating in the bathrooms. In 2018, it was possible to charge around 55 electric vehicles (EVs) in the parking houses, but within the next three years, up to 764 charging points will be available to residents on request. The housing cooperative is considering installing photovoltaic (PV) systems on some of their buildings, to be partly self-sufficient with electricity. PV generation is simulated in a parallel study [5].

2. Methods

Electricity measurements from AMS meters (Advanced Metering System) installed in 2017 and 2018 are provided by the utility company, with hourly resolution. Each measurement gives accumulated electricity delivery for the previous hour. Electricity measurements are available from 1,044 of the 1,058 apartments at Risvollan (99%), but the exact address and size of each apartment is unknown. Apartments with a measurement period of less than 80% of the year (7000 hours) were excluded from the analysis, resulting in data from 1,009 apartments (95%). When summarizing electricity use for the housing cooperative in total, average electricity use is assumed for the 49 missing apartments. Still some missing measurement periods remain, mainly in January 2018, where only 72% of the apartments are measured. From February 2018, most AMS meters are installed. There are also measurements available from 114 meters that provide electricity to common areas and EVs, with a known address for the meter locations. 25 of the meters are located in garages and 89 in other common areas. 8 of the cooperative meters have missing measurements periods of around 7000 hours, since these AMS meters were installed late in 2018. 33 cooperative meters have shorter missing periods from 400 to 2700 hours. When summarizing electricity use for the housing cooperative in total, electricity delivery is estimated for the missing periods, based on average hourly electricity delivery for each specific meter.

The electricity measurements are analysed using the statistical computing environment R [6]. From the utility company, the hourly values are marked as measured values (M) or estimates (E). 99% of the hourly values for apartments are measured as well as 98% of the values for the garages / other common areas. Since the share of estimates are so small, also the estimated values are included in the analysis, except for the analysis of max values. The data quality is evaluated as good, with few zero-values. Only one measurement error is corrected, which occurred in most apartments for two hours May 29th.

Outdoor temperatures from eKlima [7] are collected mainly from a weather station at Risvollan, where a few missing values is replaced with data from the weather station Voll, 2.5 km away. Holidays are identified as days where the primary schools are closed in Trondheim [8], including national bank holidays. If the schools are closed on a Friday or Monday, the weekends are marked as holiday-weekends. The annual seasons have three months each, where spring season starts in March.

3. Results and discussion

3.1. Electricity delivery to Risvollan in 2018

Table 1 shows electricity delivery to Risvollan in 2018. The average specific electricity delivery to apartments, garages and common areas is 56.7 kWh/m^2 heated floor area or 2,301 kWh per resident. 87% of the electricity is used in apartments, 8% in the garages and 5% in other common areas. To apartments only, the electricity delivery is 49.2 kWh/m^2 or 1,997 kWh per resident. The delivered electricity is similar to values found by [9], where average specific electricity delivery for 40 Norwegian apartment buildings is 64 kWh/m^2. Delivered heat to Risvollan in 2018 is 139 kWh/m^2, giving a total of 196 kWh/m^2 specific delivered energy. The total delivered energy is in the range of the national average for households, which is 185 kWh/m^2 [10]. Heating is 70% of the energy delivery at Risvollan, which is higher that the estimate from [9] of 60% heating share for apartments built in the period 1971–1988.

Table 1. Electricity delivery to Risvollan housing cooperative in 2018, with in total 2,321 residents.

	Heated area m^2	**# Apt (# meters)**	**Total el deliv.** MWh/yr	**Division of use**	**El pr. res** kWh/res.	**Specific el. deliv.** kWh/m^2	**Aggregated average load** kWh/h	**Aggregated peak load** kWh/h
Apartments	93,713	1,058 *(1,009)*	4,614	87%	1,997	49.2	527	1028
Garages	(16,397)	*(25)*	438	8%	189	4.7	50	104
Common areas		*(89)*	266	5%	115	2.8	30	73
Total	93,713	1,058	5,318	100%	2,301	56.7	607	1146

Abbreviations: Apt: Apartments. Res: Residents. Deliv: Delivery. El: Electricity.

Electricity delivered to apartments, garages and other common areas each hour is shown in Figure 1, as well as duration curves for the total electricity delivery. For simplification, hourly electricity delivery (kWh/h) is described as power (kW) in the figures. The highest electricity peaks in 2018 are Christmas Eve and New Year's Eve, also shown in Figure 2. Figure 3 shows the electricity signatures for apartments, garages and common areas, reflecting the relationship between electricity use and different outdoor temperatures. Since the housing cooperative is connected to district heating, the temperature dependency is rather small. Both heating and lighting are reasons for the increased electricity use wintertime.

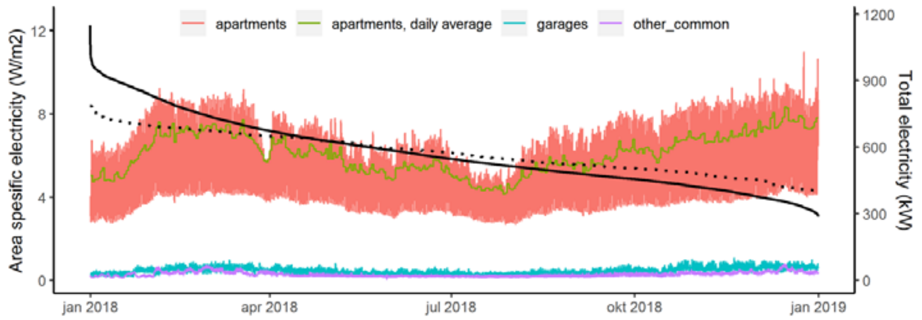

Figure 1. Electricity delivered to Risvollan housing cooperative each hour in 2018, divided on apartments, garages and other common areas. Duration curves show total electricity delivered each hour (black line) and daily average electricity per hour (dotted line).

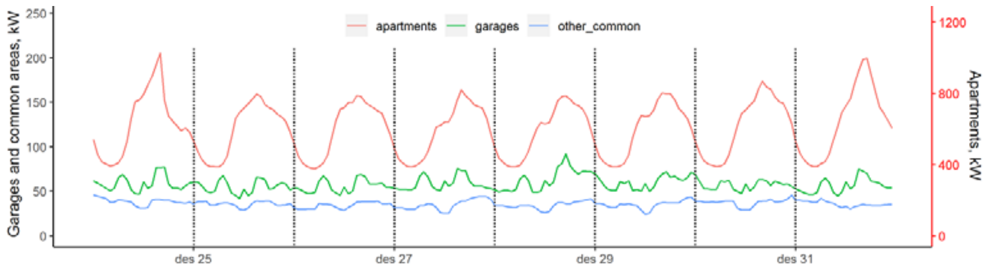

Figure 2. Electricity delivered to Risvollan housing cooperative during the Christmas week 2018, divided on apartments, garages and other common areas (scale difference of 5).

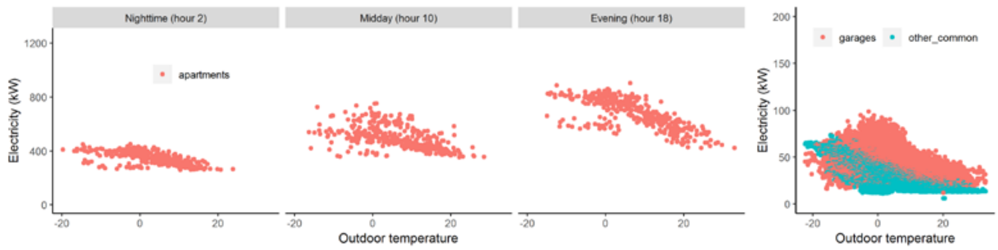

Figure 3. Hourly electricity signatures for electricity delivered to Risvollan in 2018, showing relationships between electricity use and outdoor temperature.

3.2. Variations of electricity delivery between apartments in Risvollan and coincident peak loads

Figure 4 shows variations of electricity use between 1,009 apartments in Risvollan in 2018. The average electricity delivery per apartment is 4,362 kWh, not including electricity delivery to garages and other common areas. Minimum electricity use is 324 kWh, first quartile 2,713 kWh, median 4,036 kWh, third quartile 5,642 kWh and maximum 13,654 kWh. Removing the apartments with 5% lowest and 5% highest electricity delivery, the electricity delivery varies from 1,443 to 8,391 kWh per year. Since the exact address of each apartment meter is unknown, the variations cannot be compared with area specific electricity use or number of residents, as in [11], where annual electricity use is measured in 1,300 apartments in Sweden for six years. [11] found an average increase in electricity use with increasing number of residents, but with large variations in the use. For example, variations in average electricity power for different apartments with one resident is between 80 W and 450 W, while it is between 140

W and 440 W for apartments with two residents. At Risvollan, the average electricity power for all apartments is about 500 W. There is in average 2.2 residents per apartment.

Analyzing maximum hourly values for each apartment in 2018, the average max. value is 3.2 kWh/h, see Figure 4b. The distribution of max. values in the apartments has a minimum value of 0.1 kWh/h, first quartile is 2.5 kWh/h, median is 3.2 kWh/h, third quartile 3.8 kWh/h and maximum hourly value is 7.3 kWh/h. Maximum capacity available for most apartments is 35 A or 8 kW.

The electricity coincidence factor for the in total 1174 meters is 0.323, based on hourly values. This factor is defined as the ratio between maximum load for the aggregated measurements studied (1,146 kWh/h) and the sum of each meters maximum load (3,552 kWh/h), and is always less or equal to unity [12]. The coincidence factor at Risvollan is similar to the value found by [12] for single family houses and apartment blocks, of 0.387. Looking at apartments, garages and other common electricity areas separately, the coincidence factors for Risvollan are 0.316, 0.588 and 0.624 accordingly.

The total aggregated peak load at Risvollan in 2018 is 1,146 kWh/h. To size the distribution grids, Velander's formula is widely used to calculate expected peak loads in a neighbourhood [13]. When using the formula and typical apartment blocks coefficient values as described in [13], the calculated peak load for Risvollan is 1,370 kWh/h, 20% higher than the measured peak load in 2018.

4 a. **4 b.**

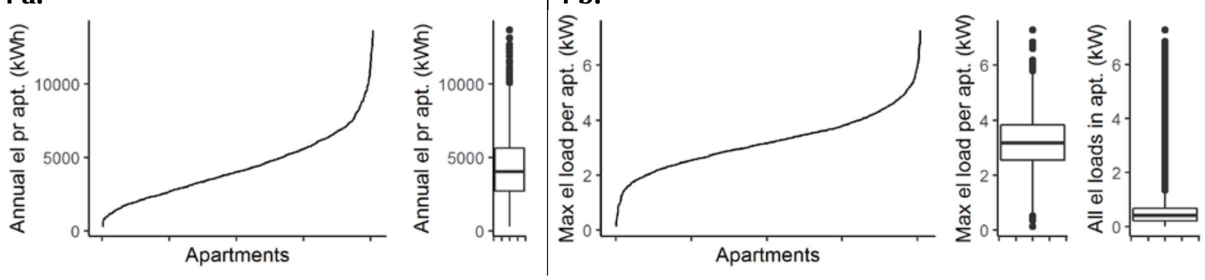

Figure 4. Variations between 1,009 apartments: Annual (a) and hourly (b) electricity delivery in 2018.

3.3. Electricity delivery to garages

The total electricity delivery to the garages was 438 MWh or 4.7 kWh/m^2 apartment area. Assuming an annual driving length of 12,000km and 0.2kWh/km, charging 55 EVs would use about 30% of the electricity delivered to the garages. Fans and lighting are among the other electricity uses in the garages. Assuming the annual driving length as above, charging the facilitated max. nr of 764 EVs would demand 19.5 kWh/m^2 apartment area. In 2018, the max hourly electricity use in all the garages aggregated was 104 kWh/h, 9% of the total aggregated peak load at Risvollan. If the number of EVs increases from todays 55 to 764, also the aggregated peak load use will increase. How the peak load will increase for the total housing cooperative, depends on the energy management and future timing of the EV charging.

3.4. Average daily electricity load profiles for Risvollan

Average daily electricity load profiles are shown in Figure 5 and Figure 6, with hourly values as the sample mean values. Apartments and garages have a similar daily profile, but with a scale difference of about 10. Both apartments and garages have an afternoon/evening peak in delivered electricity, from about 3 pm to 9 pm. During workdays, apartments have the average minimum hourly electricity delivery during night, of about 4 Wh/m^2/h, increasing to about 5 Wh/m^2/h in the morning and to 7.5 Wh/m^2/h in the afternoon, between 3 pm and 9 pm. During the weekends, the electricity delivery during daytime is higher, in average about 6.5 Wh/m^2/h from around 9 am, but with a similar afternoon/evening peak as during weekdays. The daily electricity profiles for apartments are similar to profiles found by [12], analyzing 38 single family houses and apartment blocks. The garages also have a morning peak, most likely caused by the start-up of fans and lighting when cars are collected in the garage. Figure 6 c shows the average load profiles for the 101 apartments (10%) with minimum and maximum electricity use during the year. The hourly daily profiles for the min/max apartments are similar to the average daily profile for all the apartments.

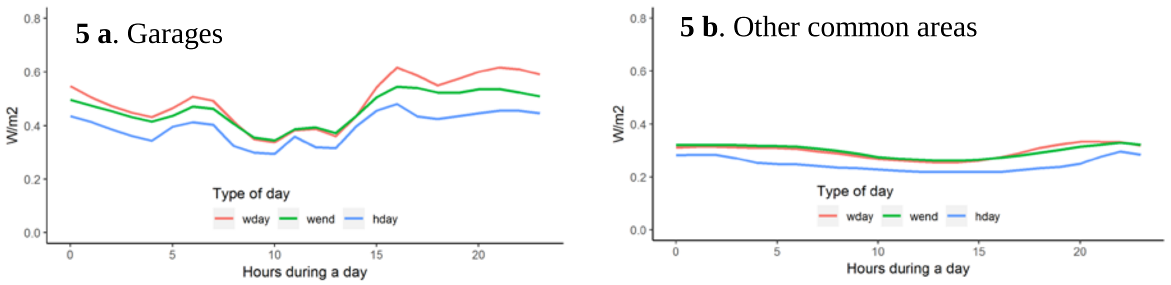

Figure 5. Average daily electricity load profiles for the common electricity delivered to Risvollan, divided on electricity to garages (**a**) and electricity to other common areas (**b**).

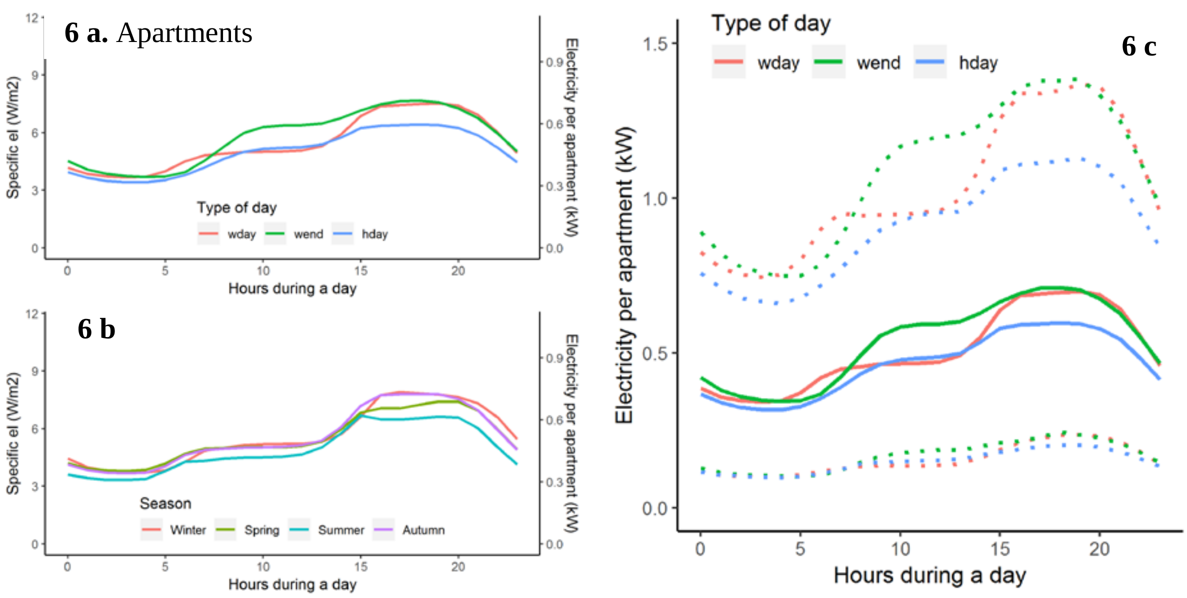

Figure 6. Average daily electricity load profiles for apartments at Risvollan in 2018, divided by weekdays and holidays (**a**), for weekdays only during different annual seasons (**b**) and average load profiles for the 101 apartments (10%) with minimum and maximum electricity use during the year (**c**).

3.5. Potential for electricity flexibility

Flexible electricity loads can be shifted in time or regulated lower or higher. How flexible a load can be, without disrupting the consumer, vary between load categories [14]. For example, changes in cooking, lighting, and television will require changes in user behaviour, while EV charging can happen independently from the user. Examples of electricity loads with flexibility potential are electric heating, electric water boilers, EV charging, washing machines and refrigerators [14], [15], [16].

EV charging is a main source of flexible electricity use in Norwegian apartment buildings. Besides often being flexible with respect to starting time, duration and charging power [17], EV charging infrastructure is the responsibility of the Risvollan cooperative, already being part of the energy management system. Electric DHW tanks are another flexible electricity load, often available in apartment blocks. Since district heating provides DHW to Risvollan, this is not relevant for this site. However, most apartments have electric floor heating in some rooms. Also, other electricity loads in the apartments can become flexible, such as dishwashers, washing machines, tumble dryers or refrigerators, which can be shifted in time. However, such electricity loads are not always easily available for an energy management system on a neighbourhood level. Batteries could be used for electricity storage, e.g. shifting electricity from the nighttime to evening peak hours. Besides stationary batteries, batteries in the EVs can be used in a V2G solution, were the battery in the EV delivers power back to the source.

4. Conclusion

As a basis for energy management in apartment blocks, this paper characterises electricity use in Risvollan housing cooperative in Norway, built in the 1970s, with in total 1,058 apartments. The average specific electricity delivery to apartments, garages and common areas is 56.7 kWh/m^2 or 2,301 kWh per resident. In 2018 the average annual electricity use in the apartments is 4,362 kWh, with variation from first quartile of 2,713 kWh to third quartile of 5,642 kWh. For maximum hourly load, the average max. value is 3.2 kWh/h, first quartile is 2.5 and third quartile 3.8 kWh/h. The average maximum load during a day is in the afternoons/evenings. The electricity coincidence factor for the in total 1174 meters is 0.323, based on hourly values. The study suggests a potential for shifting electricity loads in time on a neighbourhood level, where especially the EV charging can be utilized as a flexible load. The analysis will be used in further work, together with analysis of heat use at Risvollan, aiming to contribute to answering how effective management of power and energy at neighbourhood level can be realized.

Acknowledgements

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