IOP Conference Series: Earth and Environmental Science

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To cite this article: Tor Helge Dokka *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **352** 012061

IOP Conf. Series: Earth and Environmental Science **352** (2019) 012061 doi:10.1088/1755-1315/352/1/012061

Lia Kindergarten – A plus energy building: First year experience with regard to energy use

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Abstract. Lia kindergarten is designed to be a plus energy building. The kindergarten was opened in January 2018, and the first year has been a tune-in phase for the technical systems. The plus energy concept consist of a well insulated building envelope, a highly efficient ventilation system, a lighting system with LED-fixtures and advanced control system and a low exergy thermal energy supply based on geothermal wells and a small inverter heat pump. The energy demand is balanced with a solar PV-system on the roof to achieve the plus energy definition. A lithium-ion battery package of approximately 40 kWh has been installed for peak shaving and to utilize more of the solar energy produced on the building (reducing mismatch).

A lot of research, calculations and simulations has been done in the design phase for the low exergy system. The floor concrete slab with embedded heating (pex pipes) is designed for very low temperature heating (22-28 ^{0}C). The floor system is reversed in the summer providing high temperature cooling (18-19 ^{0}C) which also charge the geothermal wells for the heating season. The calculations and simulations has also been used to make control strategies based on model predictive control (MPC) methodology, also taking in on-line weather forecast.

1.0 Introduction

Lia kindergarten has a heated floor area of 1579 sqm and is designed as a plus energy building according to the Futurebuilt definition [1]. It is a two storey building with a flat roof, and the form of the building is basically rectangular as shown in figure 1. The kindergarten is divided into 10 departments, each having a base room approximately 30 sqm large.

Figure 1. Lia kindergarten, picture taken from the south side of the building.

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1.1 Design intent

The energy- and indoor climate concept to achieve the plus energy ambition is based on experience from earlier plus energy project like Powerhouse Kjørbo [2], but with some modification. The concept have main focus on reducing the energy demand as much as possible, without sacrificing good indoor climate, before balancing this with a cost effective PV-system. Main measures in the concept is:

- A highly insulated building envelope, with high performance windows and a low air leakage number
- Ventilation is provided by a low pressure demand controlled ventilation system based on the displacement ventilation principle. The AHU is equipped with a rotary wheel heat exchanger and an internal heat pump which heats and cools the supply air when necessary.
- Lighting is provided by a modern LED-lighting system with presence- and daylight control system, giving a very low energy system.
- Room heating and room cooling is provided with a so-called "Lowex-system", meaning that low temperature heating and high temperature cooling is done with an embedded floor system. Geothermal wells together with a heat pump provide heating and DHW, while free cooling via the geothermal wells provide cooling in the summer months, which also recharge the wells before the heating season. The low temperature heating and high temperature cooling should potential give a system with very high coefficient of performance (COP) and energy efficiency ratio (EER).
- A flat roof PV-system with modules facing East and West with an angle of 10^0 is designed so the building reach the plus energy ambition.

Main design data for the plus-energy kindergarten is given in table 1. The building is close to the requirements in the Norwegian passive house standard NS3701 [3], but deviate on a couple of the minimum requirements given in the standard.

Table 1. Main design data for the plus-energy kindergarten

Component	Value
U-value external wall	0.17 W/m^{2}K
U-value roof	0.19 W/m^{2}K
U-value external wall	0.10 W/m^{2}K
U-value windows and doors	0.79 W/m^{2}K
Air leakage number	0.50 ach
Specific fan power	0.70 kW/(m^3/s)
Annual energy use lighting*	6.1 kWh/m^2
Annual energy use plug loads	5.2 kWh/m^2
SCOP heat pump DHW	3,0
SCOP heat pump heating	5,7
SEER free cooling system	60
Geothermal wells	3 wells a' 280 m
Peak power PV-system	47,2 kWp

2. Methods

This section describes briefly the simulation tools used in the design of the building, and also the different measurements and monitoring tools used to evaluate the real performance of the building.

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2.1 Simulation tools

The energy building simulation tool Simien 6.0 [4] has been used to simulate design heating and cooling load, power demand, net energy demand and delivered energy use. It has also been used to simulate the PV-production and mismatch between production and demand based on a time step of 15 minutes (an electric balance with a resolution of 15 min).

The PV-simulation tool PV-sol [5] was used by the supplier of the PV-system to simulate the monthly and annual PV-production. Results is not shown in this paper, but the agreement with the Simien simulation was good.

Based on heating and cooling loads from the Simien simulations the geothermal wells was designed by using simulations in the tool EED-Earth Energy Designer [6]. A version based on a time step of 1 hour was used, giving hourly supply temperature from the wells.

The models in SIMIEN is based on the heating and cooling load is controlled after the room air set point temperature. Due to the large thermal inertia of the embedded PEX-pipes in the concrete slab, the heating load is controlled after the slab mass temperature, and the results from SIMIEN will therefore be inaccurate in many situations. A stationary model based on ISO 11588-2 [7] for embedded systems has been used to make model predictive control (MPC) algorithms implemented in the control system of Lia kindergarten. This stationary model has been extended to a transient model (hourly time step) by using electric analogy models similar to does used in SIMIEN. The transient model has been used to evaluate if the MPC-algorithm, based on the stationary model, is appropriate under different scenarios.

2.2 Measurements and monitoring tools

The energy- and indoor climate performance of the building is monitored by a few different systems. The main is the central operation system based on the Siemens Desigo CC system [8]. The Desigo system has a continuous monitoring of temperatures, mass flows, air flow rates, pressure losses and electric- and thermal energy meters. The Desigo system also have imported data from the PV-inverter system, giving the real time and aggregated PV-production. Due to a failure in the server system where monitored data are stored, we only have trend data (historic data) from 9th of January 2019. Before this date we only have aggregated energy use for the total operational period for the building (from early November, 2017). To get as much informative data as possible, we have chosen the period 1st of May 2018 to 30th of April 2019 for our analysis.

Another system used in analysis here is the building energy monitoring system Optima [9]. This system uses the data from the electricity meter which is collected in the elhub system (https://elhub.no/). The electric energy use and the surplus exported solar power can be reported on an hourly, daily, weekly, monthly or annual basis.

To analyze the heat pump system in detail the Nibe Uplink system (https://www.nibeuplink.com/) has been used. Due to problems with a firewall system only "manually" logged data directly from the heat pump system has been used for a limited period to assess the performance of the heat pump.

The battery system installed in the building has not yet been implemented in the Desigo system, and we have therefore no data on how this system performs. The battery performance is therefore not reported in this paper.

2.3 Climate data

Climate data used in the SIMIEN simulation is based on the normalized climate data set for Oslo defined in NS3031:2014 [10]. The annual average temperature in this climate file is 6,3 °C. The measured average outdoor temperature for the chosen period (May18-April19) was 8,7 °C. The summer of 2018 was unusually hot, but also the winter 2018/2019 was warmer than the normalized climate data used in the simulation. As discussed in Dokka&Grini [11] a simple degree day correction of energy use will be inaccurate for these kind of high performance buildings, and a simulation with real climate data was out of the scope for this study. Therefore no correction for the measured and simulated energy use has been done. Based on this we will expect the simulations of net space heating to be somewhat overestimated, and the simulation of the net space cooling to be somewhat underestimated.

3. Results and discussions

The different results from simulations and measured performance is shown and discussed below.

3.1 Total electricity use and export

In an all-electric-building like this kindergarten, where all the energy supply and production is electricity, the electric demand of the building is covered either by solar power used in the building or delivered electricity from the grid (bought). Figure 2 shows the measured electric balance of the building, where solar covers a large part of the electric demand from April to September, while the six months from October to March to a large degree is covered by grid electricity. Comparing the measured numbers with the simulated numbers (fig. 3) we see that the simulated numbers is less than half of the measured ones, and the difference is larger in the winter than in summer. One of the reasons for the high winter electric energy use is caused by the ventilation system "by accident" has been running 24/7 after a fire exercise from early November 2018 until it was corrected in February 2019. An analysis indicate that the electric demand in the winter months (Nov-Feb) would be reduced from 8 000-10 000 kWh down to approximately 5500-6000 kWh with correct operation of the ventilation, resulting in a reduction in electric energy use of approximately 14 400 kWh/a (or 9 kWh/m^{2}yr). Other reasons for the difference in measured and simulated results will be discussed in the later sections. The annual specific measured electricity demand is 46 kWh/m^{2}yr, while the simulated value was 22 kWh/m^{2}yr. The annual specific measured solar used in the building is 11 kWh/m^{2}yr, while the simulated value was 10 kWh/m^{2}yr. The annual specific measured electricity from grid is 35 kWh/m^{2}yr, while the simulated value was 12 kWh/m^{2}yr.

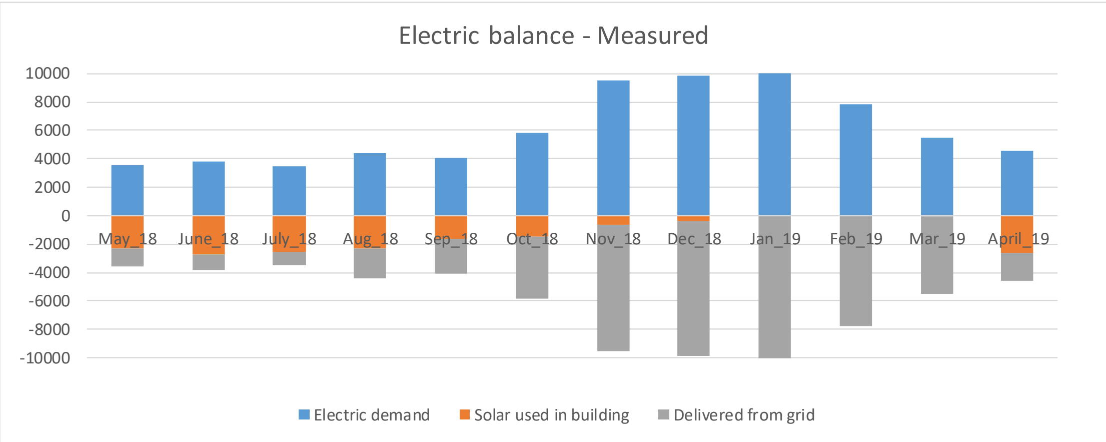

Figure 2. The measured monthly electric balance of the building.

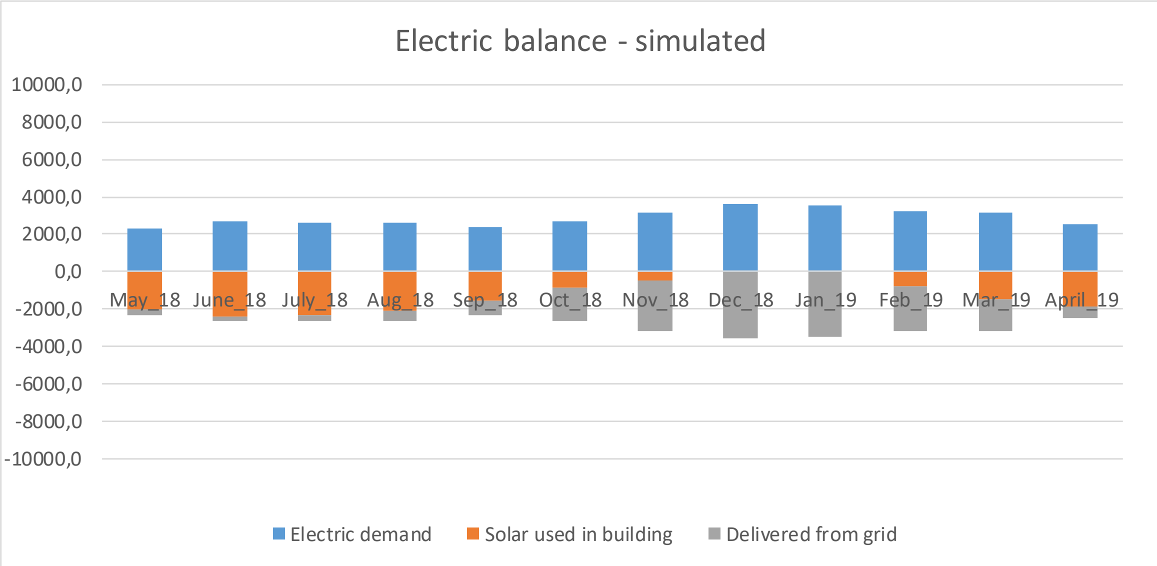

Figure 3. The simulated monthly electric balance of the building.

3.2 PV-production and mismatch demand and production

Figure 4 shows the measured monthly PV-production and the split between the use in the building and solar exported to the grid, and figure 5 shows the simulated figures. The simulated and measured numbers are overall in good agreement, however the snow cover in February and March is reducing a potential significant production in these months. How much snow cover is affecting the PV-production will of course vary from year to year, but the assumption of snow cover from 1st of December to 15th of February used in the simulations could maybe be extended one month (to 15th of March). The annual measured PV-production is 31 700 kWh, while the simulated value was 36 150 kWh. The annual measured solar used in the building is 16 780 kWh (53 %), while the simulated value was 15 890 kWh (44 %). The annual exported solar power to the grid is 14 900 kWh, while the simulated value was 20 260 kWh. That means the measured mismatch between demand and production is less than the simulated mismatch. This can probably be explained by the electric demand is higher than expected in the building. A measured performance closer to the plus energy ambition would most likely lead to more mismatch between demand and production.

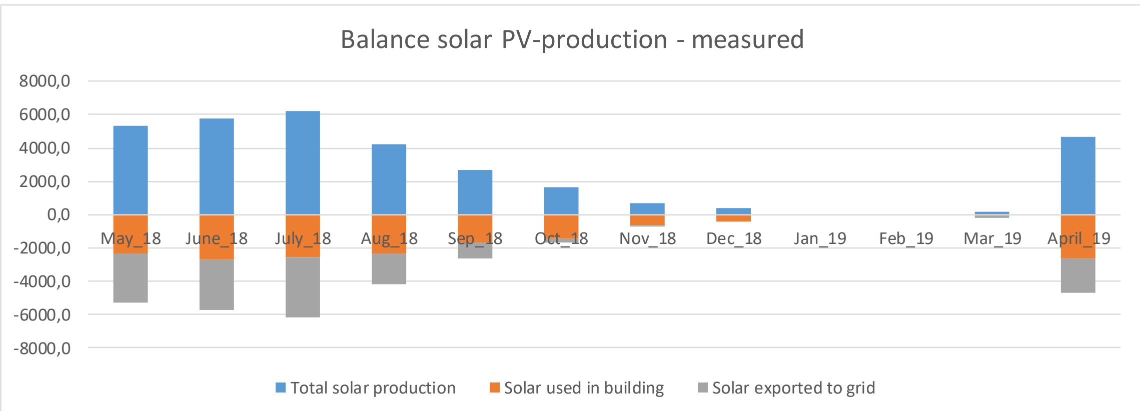

Figure 4. The measured solar PV production and split between use in building and exported to the grid.

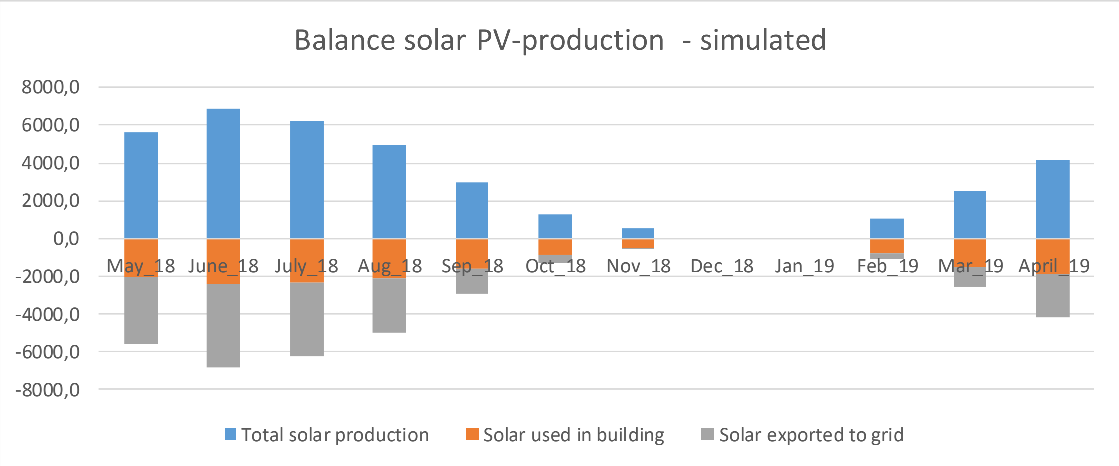

Figure 5. The simulated solar PV production and split between use in building and exported to the grid.

3.3 Net energy demand

Figure 6 shows the comparison between the measured and simulated net energy demand. The space heating from the heat pump and DHW measured by thermal meters, while the other energy items is measured by electric meters. The simulation of net energy demand does not take into account losses in distribution system.

The comparison shows that the main difference in net energy demand between simulation and measurements is due to space heating and heating coil. The primary reason for high space heating is due to the 24/7 running of the ventilation system, as described in section 3.1. Secondary reasons could be increased heat loss through the slab on ground in the first storey which the simulation model does not take into account, and also losses in the distribution system could be significant.

The net energy demand for the heating coil in ventilation system is also very much higher than the simulated value. However, we do not have reliable direct measured values of the heating demand, only electric energy use for the compressor in the internal heat pump in the air handling unit (AHU). The net demand for the heating coil is estimated by assuming a COP of 3. And in addition the compressor energy in the summer season is also included in the measured compressor energy, which due to the failure of the Desigo server system can't be deduced. Short term monitoring of the heating coil-system indicate that it "kicks in" at relatively moderate outdoor temperatures, when the rotary wheel exchanger should be more than enough to keep the desired supply set point temperature. Indicating a non-optimal control strategy of the AHU.

The net energy demand for DHW is somewhat lower than the expected (normalized) value, a trend we also have seen in other projects [2].

Energy use for fans is higher than simulated, but can largely be explained by the 24/7 running of the ventilation system from November to February. The measured specific fan power (SFP) is approximately 5 % higher than the simulated value, which corrected for the 24/7 operation is consistent with the measured energy use for the fans.

Pumps is not measured directly, but a common electric meter in the control panel measures pumps and other automation equipment. The measured energy use is therefore probably overestimated, but still quite close to the simulated value.

Energy use for lighting is measured to be appr. 9 kWh/m^{2}yr which is higher than the simulated value of 6 kWh/m^{2}yr. Short term measurements indicate that the power demand for lighting in the normal operational hours (06-18) is as designed. However, it seems like cleaning personnel trigger the light system in the evening and to some extent in the weekend, and this causes the extra energy use for lighting.

The energy use for different plug loads is not measured directly, but is the residual electric energy use when the total electricity demand (measured) is subtracted all the other measured electricity loads. The measured values are somewhat higher than the assumed plug load used in the simulation.

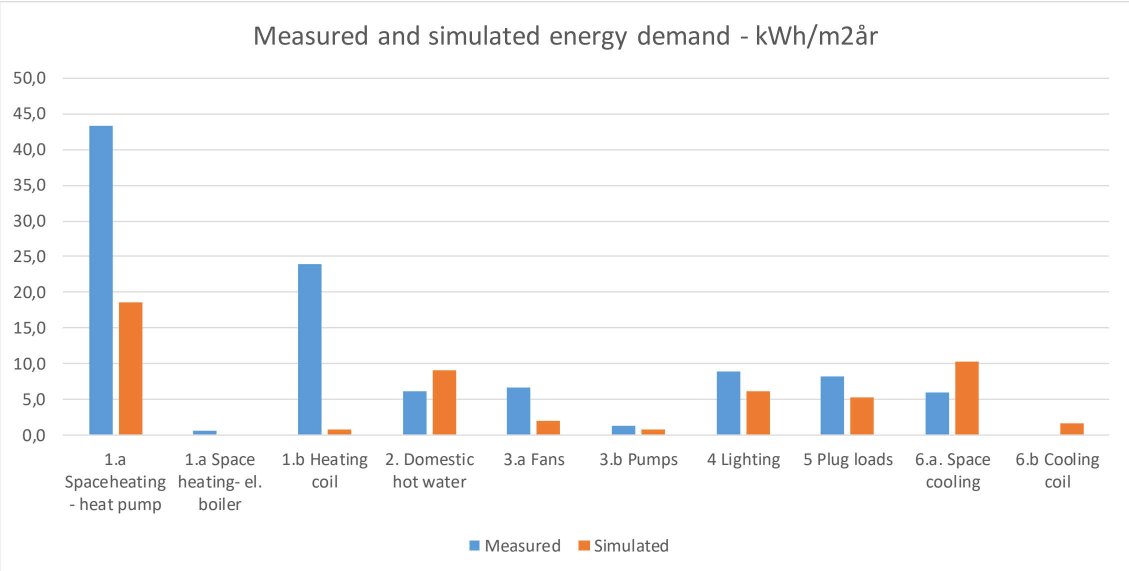

Figure 6. Measured and simulated net energy demand.

The measured space cooling load is approximately 60 % of the simulated cooling load. Reasons for this could be that solar shading and window airing is used to a larger extent than assumed in the simulations.

3.4 Performance of the lowex-system

Based on measurements of the thermal energy meters for space heating and DHW, and the electric meter for the heat pump system in the Desigo–system, an overall COP can be calculated. However this COP includes the internal circulation pumps (brine and water side) and also the internal electric element used early in the startup process of the building (late 2017). Be analyzing data from the Nibe Uplink system, this energy use for circulation pumps and the electric element could be estimated, and the COP of the heat pump (compressor) in the DHW-mode and the heating mode could be estimated.

The seasonal coefficient of performance (SCOP) for the DHW-mode of the heat pump was calculated to be 2,8. This is close to the designed SCOP of 3,0 used in the simulation.

The SCOP of the heat pump in heating mode was calculated to be 4,5. This is lower than the design calculation used in the simulation of 5,7. One reason for the lower SCOP is the supply temperature for wells in the heating season which was measured to be at average 3,0 °C instead of 5 °C calculated by the EED-simulations. The plausible explanation of the lower well temperatures is the fact that the heat balance of the geothermal wells is worse (heat dominated, lower cooling load than estimated) than used in the EED-simulations. Another factor is the supply temperature into the lowex system during the heating season, which is higher than simulated due to different flows for the external and internal circulation pumps. To balance the flows a shunt connection mixes supply and return, leading to a demand for higher supply temperature out from the heat pump. A lower source temperature and a higher supply temperature out from the heat pump of course lead to a reduced COP of the heat pump system.

The seasonal energy efficiency ratio (SEER) of the free cooling system in summer time has not been possible to measure exactly due to unreliable pump measurements. However, short term monitoring of pressure loss and flow rates for both the brine and water side during normal operation indicate the SEER simulated for the design (SEER = 60) could be reached also in practice.

3.5 Delivered energy and net delivered energy

Figure 7 shows the need for delivered energy (electricity) for the building, where measured and simulated values is compared. The efficiency (SCOP and SEER, see section 3.4) of the thermal system is taken into account here, but the solar production of the PV-system is not included. The total measured value of 45 kWh/m^{2}yr is more than twice the simulated value of 21 kWh/m^{2}yr. The reason for the gap between the designed (simulated) and real performance is explained in the sections above.

With a measured solar production of 20 kWh/m^{2}yr, the net delivered energy to the building is 25 kWh/m^{2}yr. The simulated design intent was – 1 kWh/m^{2}yr (net exported to grid). A rough analysis indicate that it would be possible to reduce the net delivered energy to the half, around 12-13 kWh/m^{2}yr by tuning and close follow-up operation of the technical system. However, to reach the plus energy ambition different hardware updates of the system would probably be necessary.

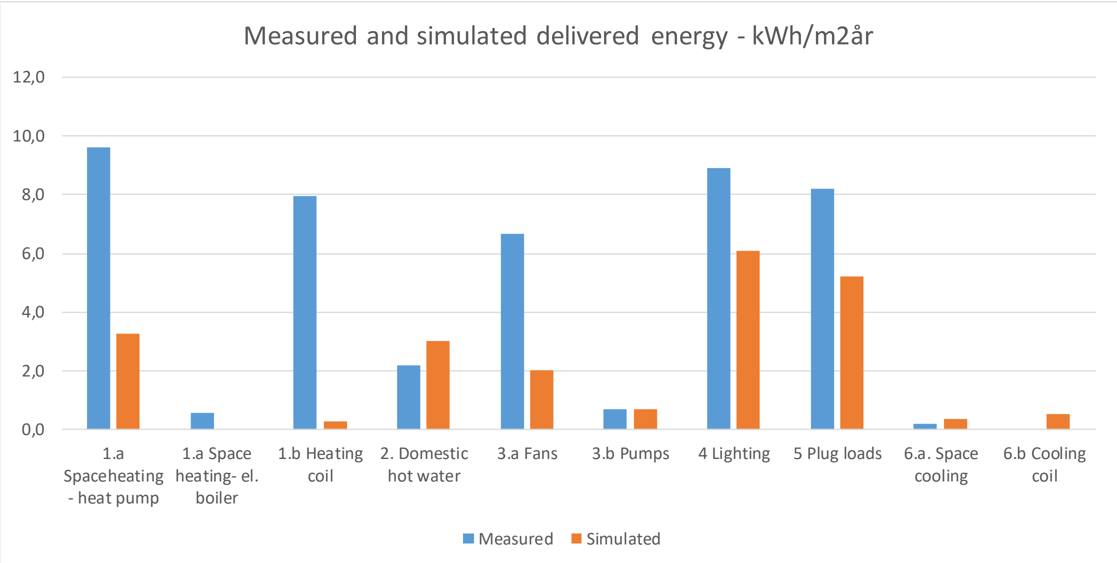

Figure 7. Measured and simulated net energy demand.

4. Conclusions

Even though the plus energy ambition is not fully met the energy performance of the kindergarten is by far the most energy efficient kindergarten the building owner (Omsorgsbygg) have. It will be possible to reduce the energy use even further than this first year of operation with tuning of the different subsystems, and close follow-up of the technical installation. To come down to the plus energy ambition in the design intent, also different hardware upgrades would be necessary.

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One of the lessons learned is the internal heat pump system in the air handling unit seems not to work optimal, and a conventional coil for heating and cooling based on the geothermal system would be a better solution.

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