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Performance of BIPV and BAPV Installations in Norway

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Introduction

The number of building integrated (BIPV) and building applied (BAPV) photovoltaic systems is rapidly increasing, both worldwide and in Norway. The research community and stakeholders in the building sector seek information on the performance and reliability of PV systems in the built environment and the best solutions for maximum energy production.

This work presents results from collected information on performance characteristics and operational experiences for a representative selection of existing BIPV and BAPV systems in Norway. The work is part of a national research project [1] in collaboration with several industry partners that aims at developing robust BIPV-solutions suitable for a Norwegian climate. The project also aims at identifying the main building-technical and architectural integration challenges for BIPV, and is developing a database to disseminate the information.

Data collection

Norwegian grid-connected BIPV and BAPV systems range from small residential systems (1-10 kW_p) to commercial systems (up to 370 kW_p). From a total of more than one hundred systems, the table below shows a shortlist of cases evaluated in more detail during the project. Different geographical regions, sizes, and technologies are represented. The systems are evaluated in terms of yield, specific yield, and performance ratio (PR). The analysis follow recommended guidelines in the literature and the IEA PVPS Task 15 [2] and Task 13 [3] programs.

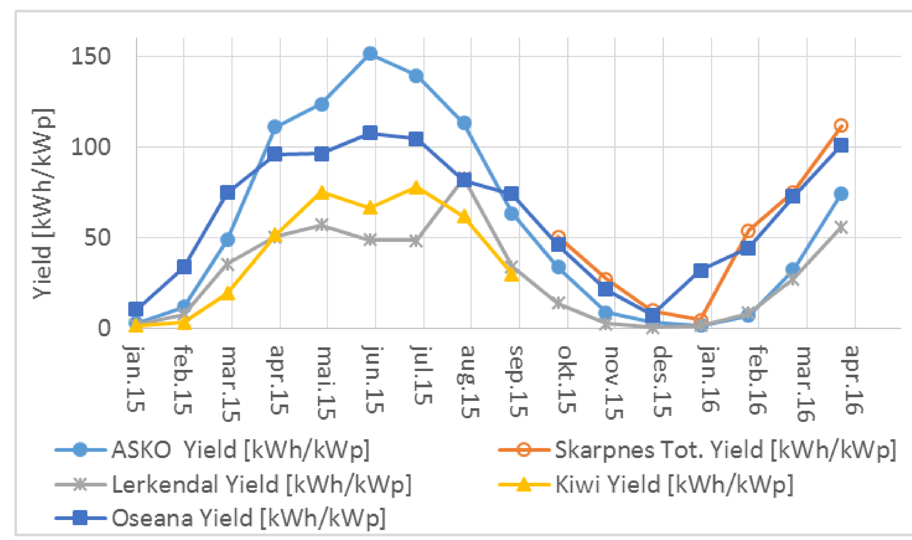
Name	Coordinates	Building purpose	Integration	PV orientation	Commissioned	Years of data coll.	Irrad. & PV temp.	DC power [kWp]	AC power [kWp]	DC-to-AC ratio
01_Oseana	60.18N, 5.47E	Culture centre	BIPV (curved facade)	Azm 190°, Tilt 0°-70°	2011-Nov	4	-	63.525	55.0	1.16
02_Haakonsvern	60.34N, 5.23E	Offices	BAPV (flat roof)	Azm 90°/270°, Tilt 10°	2015-Nov	0	-	85.000	80.0	1.06
03_AgderEnergi	58.15N, 8.00E	Offices	BAPV (flat roof)	Azm 200°, Tilt 20°	2011-May	4	Y	45.180	39.6	1.14
04_Skarpnes	58.42N, 8.72E	Detached house	BIPV (pitched roof)	Azm 42°/231°, Tilt 32°	2015-Jan/Nov	1	Y	7.360	7.0	1.05
05_Evenstad	61.43N, 11.08E	College	BAPV (pitched roof)	Azm 161°, Tilt 34°	2013-Nov	2	Y	70.380	60.0	1.17
06_AskoVestby	59.59N, 10.74E	Warehouse	BAPV (flat roof)	Azm 90°/270°, Tilt 10°	2014-Sep	1	Y	370.500	310.0	1.20
07_Haldenterm	59.13N, 11.29E	Warehouse	BIPV (facade), BAPV (flat roof)	(f) Azm 195°, Tilt 90° (r) Azm 105°/285°, Tilt 10°	2015-Sep	0	-	132.000	120.0	1.10
08_Økern	59.93N, 10.81E	Nursing home	BAPV (flat roof)	Azm 90°/270°, Tilt 10°/20°	2014-Jun	1	Y	130.000	110.0	1.18
09_PastorFangen	59.95N, 10.74E	Care homes	BIPV (pitched roof)	Azm 90°/270°, Tilt 12°	2015-Nov	0	-	63.440	71.4	0.89
10_KiwiAuli	60.03N, 11.35E	Foodstore	BIPV (pitched roof)	Azm 180°, Tilt 7.5°	2014-Nov	1	-	163.000	250.0	0.65
11_Kjørbo	59.89N, 10.53E	Offices	BAPV (flat roof)	Azm 90°/270°, Tilt 10°	2014-Apr/Aug	1	Y	311.958	244.0	1.28
12_Solsmaragden	59.74N, 10.19E	Offices	BIPV (facade), BAPV (flat roof)	(f) Azm 90°-270°, Tilt 90° (r) Azm 115°/295°, Tilt 10°	2015-Nov	0	-	183.000	166.0	1.10
13_Lerkendal	63.41N, 10.40E	Offices	BAPV (facade)	Azm 171°/261°, Tilt 90°	2012-Sep	2	-	27.225	21.7	1.25

Name	PV module	Type	Inverter	Estim. Yield (supplier) [kWh]	Meas. Annual Yield [kWh]	Estim. Specific Yield [kWh/kWp]	Avg. Meas. Specific Yield [kWh/kWp]	Deviation Specific Yield, ref Estim. [%]	Avg. PR
01_Oseana	363 x 175 W SOLPOWER GM572S-	mono-Si	Sunny Tripower, 3x15 kW, 1x10 kW	42000	47800-54500	661	800	21	-
02_Haakonsvern	254 x 333 Wp BenQ SunForte	mono-Si	SMA 4 x 20 kW	53000	-	624	-	-	-
03_AgderEnergi	166 x 225 W REC, 24 x 225 W Sunt	poly-Si, a-S	Eltek Theia, 9 x 4.4 kW	40000	40900-43900	885	937	6	0.74
04_Skarpnes	32 x 230 W SunPower SPR NE-BLK	mono-Si	SMA Sunny Tripower, 1 x 7 kW	6800	-	924		-	-
05_Evenstad	276 x 255 W REC 255PE 01/2013	poly-Si	SMA SunnyBoy, 12 x 5 kW	60000	62500-63300	853	895	5	-
06_AskoVestby	1482 x 250 W IBC Solar PolySol 2	poly-Si	Sungrow SG, 2x20 kW, 9x30 kW	300000	300000	810	810	0	0.86
07_Haldenterm	501 x _ IBC (roof), _ (facade)	poly-Si	Sungrow, 6 x 20 kW	100000	-	758	-	-	-
08_Økern	500 x 260 W REC 260PE	poly-Si	Eltek Theia, 25 x 4.4 kW	105000	94000	808	723	-10	-
09_PastorFangen	244 x 260 W PolySol IBC Solar	poly-Si	Powador 6x9.6 kW, Blueplanet 3x4.6 kV	51800	-	817	-	-	-
10_KiwiAuli	1663 x SUNSTYLE PV roof tiles	mono-Si	Eltek Theia	97000	-	595	-	-	
11_Kjørbo	954 x 327 W Sunpower E20/327	mono-Si	SMA Tripower, 4x12, 4x15, 8x17 kW	229300	221400	735	710	-3	-
12_Solsmaragden	979 x _ Issol, 242 x 280 Wp IBC	mono-Si, po	SMA, 13 x STP (3-25 kW)	106000	-	579	-	-	-
13_Lerkendal	121 x 225 W Solartek PVP22530	poly-Si	Sunny MiniCentr. 4x5 kW, 1x1.7 kW Sun	14291	10400-14400	525	406 (530)	-23	(0.58)

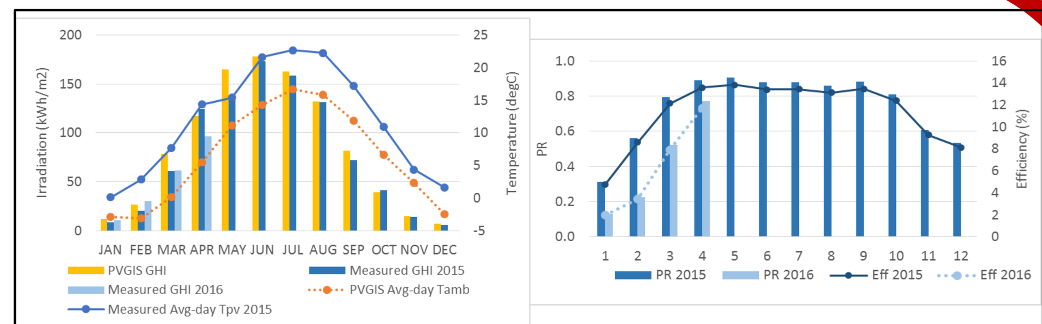
A questionnaire has been developed to interview key personnel involved in the design, installation and operational phases. The current work presents five selected cases in more detail, which provide valuable lessons learned in terms of system performance and architectural or building-technical integration issues.

Results

Estimated (blue values) and measured (black values) annual specific yield (in kWh/kW_p) for the systems shown in the table (left).

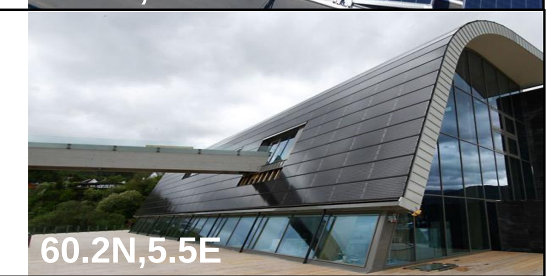


Comparison of monthly specific yield for five selected cases (photos to the right).



Roof BAPV
ASKO Vestby
370.5 kW_p poly-Si
Azm 90/270º, tilt 10º

Façade BIPV
Oseana
63.5 kW_p mono-Si
Azm 190º, tilt 0-70º



Façade BAPV
Lerkendal
27.2 kW_p poly-Si
Azm 171/261º, tilt 90º

Roof BIPV
Kiwi Auli
163.0 kW_p mono-Si
Azm 180º, tilt 7.5º

Roof BIPV
Skarpnes
7.4 kW_p x 5 mono-Si
Azm 42/231º, tilt 32º

The data collected and analysed so far indicates some spread in performances, partly as expected due to differences in system design and the available solar resource, but also due to non-optimal site conditions and shading challenges. Current installations predominantly employ well-known crystalline silicon technology, and rooftop BAPV installations are still more common than BIPV.

Comparing **measured** with the **estimated** specific yield (usually determined by software simulation in the design phase), the deviation varies from a few percent to above 20 % in the different cases, where both over- and underestimation is seen. Typical measured annual specific yield is in the range 700-900 kWh/kW_p. For one case of a rooftop BAPV system with slightly tilted modules, an annual PR of 0.86 was achieved in 2015. This is comparable with values seen elsewhere in Northern Europe [4]. Much lower PR is seen for systems severely affected by shading.

Conclusion

The results and lessons learned so far point at the importance of including knowledge about PV system design and operation into the early planning process of a building project. This may help to avoid shading problems and added costs during the installation phase caused by difficult weather conditions, complex surface curvatures, layout changes, or deviations between actual and as-planned dimensions.

The performance evaluation is currently limited by scarce irradiation data. In new installations, the project partners are encouraged to install basic monitoring instrumentation that allows evaluation of performance parameters. This will provide better estimates of PV performance for planning purposes, and give valuable input for the development of new guidelines and robust solutions for the growing BIPV market.

[1] *Building Integrated Photovoltaics for Norway*, EnergiX project no. 244031, The Research Council of Norway, www.bipvno.no
[2] IEA PVPS Task 15:*"Enabling Framework for the Acceleration of BIPV"*. http://iea-pvps.org/index.php?id=task15.
[3] IEA PVPS Task 13:*"Performance and Reliability of PV systems"*. http://iea-pvps.org/index.php?id=57.
[4] A. Woyte, et al., "Monitoring of Photovoltaic Systems: Good Practices and Systematic Analysis", in *Proc. 28th EUPVSEC*, Paris (2013):3686-3694.

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