PV QUALITY ISSUES APPLYING BUILDING INTEGRATED PHOTOVOLTAICS (BIPV) ON THE FACADE AND ROOF WHEN DEEP RENOVATING A 50 YEAR OLD APARTMENT BUILDING

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ABSTRACT:
Kollektivhuset Stacken, a classic, 50-year old Swedish “million program” building with 35 apartments in Göteborg, which has long been run as a cooperative, has demonstrated a cost effective step by step deep retrofit to the international Passive House standard with a building integrated PV (BIPV) façade and roof. The existing concrete façade was externally insulated and covered with thin film amorphous silicon solar modules and more effective crystalline silicon solar modules were installed on the roof. New passive house certified doors and windows, demand-controlled ventilation coupled to a heat recovery unit and vacancy sensor based lighting was installed throughout the building. Finally, sensors to monitor the solar arrays, as well other parameters such as cold and hot water use, ventilation flows, electricity, temperature and humidity in each apartment were also installed.

The research project presented in this article is a collaboration between Göteborgs University, RISE, and Emulsionen that uses knowledge and data gathered from the project towards evaluation of the performance and reliability of the BIPV system.

Keywords: BIPV, renovation, apartment building, solar modelling

1 INTRODUCTION

Sweden has an ambitious political goal to be net zero greenhouse gas emissions (GHG) by 2045 which is in line with the EU’s goal that the building sector as a whole should reduce GHG emissions by 80% by 2050. A determining factor in reaching these goals in Sweden is the “million program” buildings, a name given to the (mostly) prefab concrete buildings built in the 60s and 70s to reach a goal of one million additional homes[1]. These buildings are in great need of renovation today, and that poses both a problem and an opportunity[2]. Namely, there is a lack of cost effective renovation solutions that both reduce energy demand and generate renewable energy.

1.1 Background

Building Integrated Photovoltaics (BIPV) applied on roofs and façades of existing buildings during renovations is one such potentially cost-effective solution. If one looks at only the roof area for all buildings in Sweden (approx. 1100 km^2)[3], the contribution to total electricity production would be on the order of 80 TWh per year, which is more than half of Sweden’s total electricity use. If this type of solar capacity was installed on the Swedish building stock gradually as roofs and façades were renovated the extra cost to society would be vanishingly small since the price of some solar modules (20-30 €/m^2) are now cost competitive with traditional façade and roof materials[4].

When BIPV is part of a thermal envelope renovation the energy use in the building can also be reduced by 50-80%, and up to 100% of the remaining energy demand can come from the BIPV. So, a BIPV product that can replace traditional building materials such as fiber reinforced concrete, sheet metal, bricks and fiber polymer boards opens up a large potential to improve energy performance of buildings (mostly through insulation and airtightness) and at the same time reduce the environmental impact of the electricity generation system as a whole (with PV). The challenge is to create a BIPV system that is inexpensive to install, fulfills the façade and roofs’ functions without compromising the solar modules production, and has a low life cycle embodied energy.

1.2 The pilot project

Kollektivhuset Stacken, a 50-year old building with 35 apartments in Göteborg, Sweden, which has long been run as a cooperative, has demonstrated a cost-effective step by step deep retrofit to Passive House standard with a building integrated PV façade and roof.

The technical goals of the renovation were to reduce space heating demand to below 15 kWh/(m^{2}a) (i.e. to international Passive House Standard) and electricity consumption to approximately 30 kWh/(m^{2}a) while achieving a highly comfortable indoor climate with good air quality and comfortable surface and air temperatures.

To achieve these results the existing concrete façade was externally insulated and covered with thin film solar modules and more effective crystalline solar modules were installed on the roof. New passive house certified doors and windows, and demand-controlled ventilation coupled to a heat recovery unit have been installed in the building. Finally, sensors to monitor the solar arrays, cold and hot water use, ventilation flows, electricity, temperature and humidity in each apartment were installed. Installation of vacancy sensor based lighting is still underway and final ventilation adjustments have not yet been completed as of the time of publication of this article.

The pilot project was led by members of Kollektivhuset Stacken in partnership with Chalmers Tekniska Högskola, Passivhusbyrån, Helhetshus architect studio, Rockwool, i2 Smartwin, Passivhuscentrum, and Ekobanken. Financers for the construction include Naturskyddsföreningen, Energimyndigheten, and Västra Götalandsregionen. Technical support has been provided through inclusion in EuroPHit, a Passive House project of the European Union. Figure 1 shows the completed building in its surroundings next to identical unrenovated buildings on the same street.

Figure 1: Kollektivhuset Stacken with BIPV façade and roof next to neighboring unrenovated “star” buildings. Photo courtesy of Badenfelt and RISE.

This article aims to summarize the testing of solar modules used in the project, technical problems encountered with the BIPV system, and compare actual performance to modelled typical year projected performance. A financial review of this retrofit BIPV concept is also presented.

2 METHODOLOGY

The analysis presented here is a comparison between the modelled and measured production data from the BIPV array, as well as results of IV-curve efficiency testing at STC (so called “flash testing”) of the modules. Although the system began producing power in October 2017, and one calendar year is used for simulating performance, measured data from the PV system is only available for a period of about 3 months from the middle of May until the middle of September, 2018, due to a variety of problems with metering the system. Additionally, due to various equipment and design problems including reorganization of the layouts the solar arrays, the arrays did not reach their final state until the beginning of September, 2018. Therefore, the time period with metered production data includes periods when parts of the roof solar array were out of commission.

2.1 The building model

The building energy model is done in the Passive House Planning Package (PHPP)[5] and the solar energy production model in System Advisor Model (SAM)[6] with a 3D modelling scene developed based on a combination of satellite images and on-site measurements of shading objects. Solar irradiance data is from PVGIS5 including calculated horizons for the site[7].

The facade modules are simulated using the IEC 61853 diode model in SAM with module parameters populated from PVSyst, whereas the roof modules are modelled using the CEC model (with user entered parameters from the manufacturer datasheet) in SAM.

21 blocks of modules with expected production of a maximum of 6kW DC are attached to 21 DC-DC optimizers, each with an MPPT, and modelled as separate cases in SAM, each with an appropriate 3d shading scene. The number of strings per optimizer on all but the north facade is 11 on the upper facades, and 13 on the lower facades. The north façade has 24 parallel strings connected to one DC-DC optimizer. To conform to the input requirements for SAM each of the 6kW DC-DC optimizers is modelled as a 6kW inverter, and each string is modelled separately in the 3D scene. In reality, the output from the 21 DC-DC optimizers is transmitted over a 760V bus to a central inverter in the building, with a capacity of 56 kW AC. A typical façade string layout is shown in figure 2.

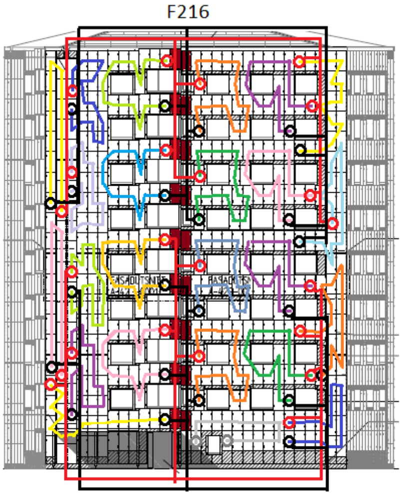

Figure 2: String layout of the southwest facing façade.

2.2 Flash testing of the solar modules

Amorphous silicon GS Solar GS-50 frameless laminated glass modules were chosen for the facades due to their low price per square meter (20 – 30 €/m^2) and the added benefit of having a uniform appearance similar to a standard glass façade.

A combination of monocrystalline silicon Enfinity 185M5-L frameless single glass modules (BIPV) and polycrystalline silicon PPAM Paladium 325 framed modules (BAPV) were chosen for their higher efficiency on the roof where solar irradiance per area is also higher.

The BIPV photovoltaic modules were characterized in a pulsed sun simulator Endeas QuickSun 560Ei class A+,A,A+, according to IEC 60904-1 chapter 4.2. The sun simulator (flasher) was calibrated using the short circuit current on a reference module before the measurements. The reference module was calibrated at Fraunhofer ISE traceable to World PV Scale. The results were corrected to STC standard test condition according to IEC 60891.

3 RESULTS AND DISCUSSION

Table I: GS Solar GS-50 façade module testing.

Facade modules ¨	I_{sc} (A)	I_{mp} (A)	V_{oc} (V)	V_{mp} (V)	P_{mp} (W)
average 10 modules	1,58	1,35	64,2	49,2	66,4
Std. dev. 10 modules	0,07	0,04	0,55	0,55	2,5
max	1,7	1,4	65,6	50,1	72,6
min	1,5	1,3	63,8	48,2	64,8
Deviation from marking	11%	15%	4%	14%	33%

Table II: Enfinity 185M5-L roof module testing.

Roof modules	I_{sc} (A)	I_{mp} (A)	V_{oc} (V)	V_{mp} (V)	P_{mp} (W)
average 19 modules	5,38	5,03	44,2	35,8	180,4
Std. dev. 19 modules	0,07	0,08	0,21	0,23	2,1
max	5,48	5,11	44,6	36,4	184,9
min	5,16	4,75	43,8	35,4	177,5
Deviation from marking	-1%	-1%	-2%	-1%	-2%

3.1 Flash Testing Results

The results of the flash testing (Tables I and II) show that the monocrystalline modules were within the tolerance specified by the manufacturer (3%), but the amorphous silicon modules were significantly above that. One probable explanation for this discrepancy is that the a-Si modules were new and had not been through the rapid "burn in" period that usually occurs during the first year.

Additionally, no spectral correction was applied which can cause an increase of approximately 25% in P_{max} for a-Si but only 1% for mono-Si.

The GS Solar modules was also measured with covers to simulate clamps covering the active PV material at 4 places around the frame. No effect on the IV curve nor on P_{max} was noted.

3.2 Modelled compared to actual results

This project has broken new ground in Sweden by demonstrating that renovations of existing apartment buildings to passive house standard with BIPV facades can be done in an economical way. As such the project has faced much difficulties in both holding timelines and finding builders with the competence needed. Additionally, working with local solar equipment manufacturers has lead to a long debugging process and large amount of down time and decreased production from the solar arrays.

A lack of quality control by the builders and incomplete open circuit voltage tests during installation have made it difficult to debug production problems. Additionally, the fact that string layout has hidden most connections behind the solar panels has led to relatively costly skylifts for repairs.

The result of the first 9 months of solar production after commissioning in November, 2017 have been less than expected production. During the 3 months of June through August 2018, when measurement equipment was working, an approximately 33% reduced production was observed compared to a typical meteorological year (see figure 3).

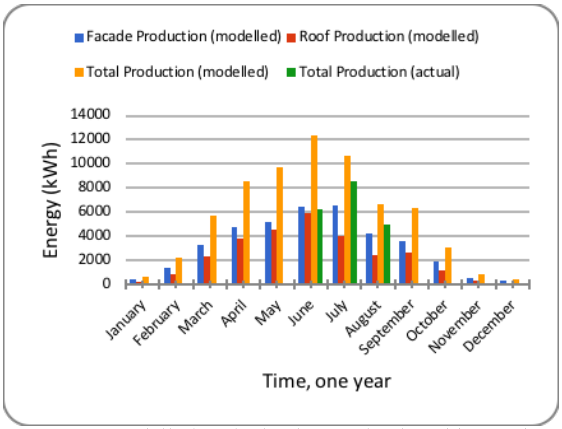

Figure 3: Modelled typical solar production (blue, red, yellow) per month "as installed" excluding parts of the array that were disconnected due to repairs, compared to measured production (green) during the summer.

The main cause to this reduction is believed to be the DC optimizer and inverters which have problems with overheating and with instability at high voltages and ambient temperatures. The equipment manufacturer is actively working on solutions to these problems.

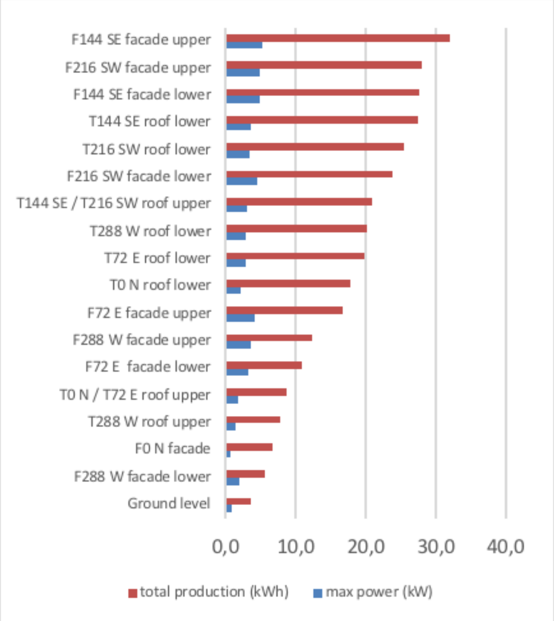

Figure 4: Solar production per DC-DC optimizer on September 2, 2018, a sunny day with global horizontal irradiance of 8kWh/m2. The DC-DC optimizers are named according to the facing direction and whether mounted on the upper or lower parts of the roof and façade. Note that total production was 315 kWh on this day.

Figure 4 shows measurements of the maximum power and energy production for a sunny day in September for each subarray. It can be seen in these results where the most and least productive subarrays are both in terms of peak power and total energy. Figure 5 shows then the comparison of modelled and measured production (both net and brutto) for the system as designed. It was not until the beginning of September, 2018 that the last subarrays were connected and put into operation.

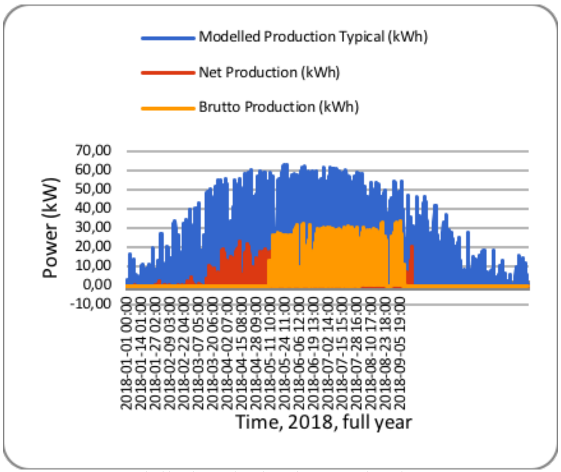

Figure 5: Modelled typical solar production "as designed" during a whole year (blue), compared to measured net production (red) and brutto production (orange) for 2018.

An attempt at using IR thermography with a drone to look for hot spots or incorrectly connected modules has not yet uncovered any results (see figure 6). We hope to continue this inspection nearer to the building to thoroughly debug the façade. The PID effect should also potentially be ruled out as a potential source of problems, although the panel manufacturer installation instructions do clearly state that there is no need for negative grounding for the amorphous silicon solar modules used in this project.

Figure 6: Thermographic imaging of Stackens BIPV facades and roof from a drone mounted IR camera.

4 CONCLUSION

Despite problems with the PV array, the concerted efforts to reduce electricity use by the inhabitants of this cooperative apartment building since the early 2010s has led to significant decreases (see figure 7) in purchased electricity culminating in the last year with the BIPV arrays completion.

With the fixes to the DC-optimizers and inverters the project should be able to attain production inline with the models.

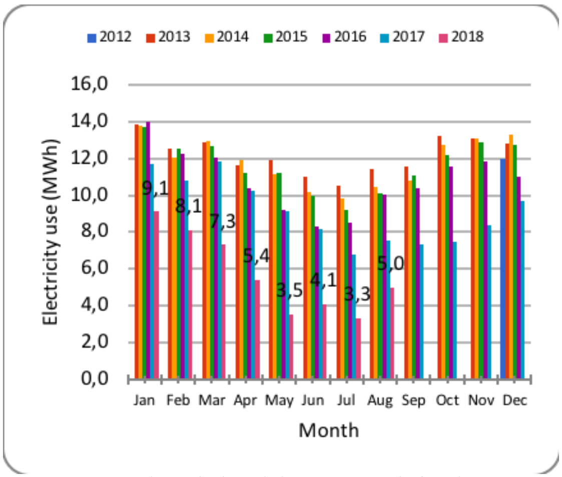

Figure 7: Purchased electricity per month for the 3500 m^2 apartment building from December, 2012 through August, 2018.

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