

BP SOLAR SKIN - A FACADE CONCEPT FOR A SUSTAINABLE FUTURE

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Abstract - A prototype solar façade system has been constructed on an existing building at the Norwegian University of Science and Technology in Trondheim, Norway. The façade produces both electricity and heat and is suitable for existing and new buildings. The system is based on a combination of a double skin facade and building integrated PV façade cladding, where the PV cells are integrated in the outer glass skin. The cells are laminated in glass, and placed in façade sections that are not in front of the ordinary windows. The performance characteristics of the two combined façade concepts are complementary –the systems help each other if controlled properly. The 455m² prototype façade is financed mainly by BP Norway and developed in cooperation with BP Solar. It has been monitored for a year with satisfactory results. The PV system generated 6600 kWh this year, and the heating demand for the building behind the new façade was reduced with 7-8%. The offices on the top floor of the building experienced summer periods of overheating, but a revision of the control strategy for the double façade cavity venting is expected to reduce this problem.

1. PROJECT BACKGROUND

BP Norge and BP Solar commissioned Norwegian research units at NTNU and SINTEF to develop a building system for facades, based on photovoltaic solar cells. The Norwegian University of Science and Technology, NTNU, and the affiliated contract research foundation SINTEF, came up with the idea of combining building integrated PV cells with a double skin façade.

A double façade, or double skin façade, consists of a glass skin mounted outside the normal insulated external wall of a building. The cavity formed between the outer skin and the main wall will provide extra thermal insulation and improved air tightness for the building. The cavity offers also a protected location for solar shading systems and other façade equipment, and platforms for maintenance, cleaning and fire escape can be introduced.

With southerly exposure, the glazed cavity will trap solar radiation the same way as a greenhouse or an atrium. The energy captured can be used for preheating supply ventilation air, the raised cavity temperature will in any case reduce the heat loss from the building. In the cooling season, the cavity will have to be vented.

Adding a double façade to an existing building will in many cases be a viable alternative to installing new windows and improving the thermal insulation, especially for historically important buildings where façade upgrading maybe not feasible. The double façade concept can also be applied to new buildings, often for the enhancement of a desired image of high-tech high profile buildings.

Applying PV cells to the building envelope is often termed Building Integrated PV, BIPV. Better economy than for stand/alone systems is often realized with this concept, as the PV modules also have other functions. At higher latitudes, the solar radiation on a vertical south-facing wall is not much less than on a sloped surface oriented optimally for maximum radiation. It is therefore feasible to integrate PV cells in the cladding of facades. The PV output is dependent on temperature, the cells should be kept cool, therefore in a BIPV application, the PV modules should be vented

2. THE BP SOLAR SKIN CONCEPT

The proposed building system is based on a combination of a double skin facade and building integrated PV façade cladding, where the PV cells are integrated in the outer glass skin. The cells are laminated

in glass, and placed in façade sections that are not in front of the ordinary windows. The performance characteristics of the two combined façade concepts are complementary – the systems help each other if controlled properly.

Some important features of the BP Solar Skin concepts are:

Both electricity and thermal energy are provided.

The PV cells convert about 15% of the solar radiation to electricity.

The thermal energy can be used to reduce the heating load of the building.

The PV cells provide solar shading for the windows for summer high sun.

The cavity can be implemented in a scheme for natural ventilation.

The cavity can be vented to keep the PV cell temperature down for better performance.

The cavity provides a protected location for solar shading systems.

The skin and the cavity will provide improved noise protection.

The cavity enables operable windows in high-rise buildings.

The cavity can be supplied with platforms for maintenance and evacuation.

The concept is well suited for thermal upgrading and climate protection of existing buildings, but can also be applied in new buildings.

The BP Solar Skin concept of course also implies some problem areas: important items are fire safety related to smoke propagation in the cavity, sound propagation likewise, reduced daylight levels, impairment of view in some configurations.

3. THE R&D STAGE

In order to assess the performance more closely and evaluate alternative designs, a comprehensive R&D project was carried out after the first conception stage. The energy performance of the façade and the thermal comfort in the building were assessed, using computer simulations, for a generic office building in various Norwegian climates. It was difficult to simulate correctly the thermal behaviour of this rather complex system; however, it was evident that optimal control of venting the cavity was of primary concern.

The architectural and visual aspects of the concept were studied using scale models, full-scale mock-ups, photomontages and computer visualisations. An important consideration was the effect of PV cell spacing in the outer skin and the apparent transparency of the whole skin from both sides. The impacts on daylight levels and glare problems were also important aspects of the research.

4. THE BP SOLAR SKIN PROTOTYPE

Based on the results from this R&D and cost estimates, BP decided to construct and monitor a full-scale prototype. An existing office building at the engineering campus of NTNU was chosen as site. A wing of the office complex for the Electrical Engineering faculty has a slightly protruding four-story façade, oriented 25° east of due south. The main part of this wing was built around 1970, with fairly poor insulation and a large amount of air leakage.

The double façade prototype was constructed with glass panels mounted in a standard aluminium framing system. The outer skin is carried by vertical steel frames, these are bolted to the concrete floors of the building. Open-grate steel platforms are installed at each floor level for monitoring, maintenance and cleaning purposes. The cavity can be vented by motor-operated vents at the top and bottom, controlled by temperature sensors.



Figure 1. Photos of the facade with PV cells.

The PV cells and the conduits are embedded in a resin layer in laminated glass modules. These modules are located outside the façade sections without windows. The cells used are of the high efficiency, mono-crystalline BP Saturn type, with an efficiency of about 16%. The PV

cells generate low voltage direct current that is coupled to the building's electricity supply via an inverter and a transformer.

The main figures relating to the prototype are:

Total façade area:	455 m ²
PV module area:	192 m ²
PV cell net area:	102 m ²
Cavity width:	0.8 m

The prototype design went through much the same analysis as was conducted in the feasibility study. A major concern was fire safety: the fire code and available fire research have little bearing on the problem of smoke propagation through the stack effect (e.g. air movement upwards due to hot air rising) in a double skin cavity. The designers, therefore, decided to install a dry sprinkler system to cool down window glazing on the existing façade in the event of fire. They also improved the fire detecting system.



Figure 2. Western part of the university campus with the new south-facing façade in the background.

5. THE MONITORING PROGRAM

The prototype is instrumented with automated monitoring equipment which registers both the electricity delivered to the building's grid, and how the solar energy facade affects the heating demand and indoor climate of the rooms that face the new facade. A weather station is located on the roof of the building. In addition to electrical energy delivered to the building, the monitoring includes surface and air temperatures, air velocity in the cavity, and position of the vents.

One year's worth of data, from May 2001 to May 2002, has been collected and analysed. The monitoring equipment will be maintained in operation after the project monitoring is completed. The data will be made available for student projects in the new NTNU engineering study programme "Energy and Environment".

The occupants in the rooms facing the new façade have been subjected to three rounds of questionnaire surveys: before construction, during a winter period, and during a summer period. Of special interest is the impact of the new façade on the thermal comfort and perceived air in the summer season. The venting through the cavity under clear sky summer conditions has therefore been the subject of special investigations as to the performance of the cavity under cooling demand conditions (Aschehoug & al., 2000).

The daylight losses due to the new glass wall was also studied before construction, included was also the impact of the PV cell spacing on the transparency of the outer skin. The daylight reduction is quite large, but the levels inside are still well within the building code requirements.

6. MONITORING RESULTS

6.1 Electricity generation

The PV cell electricity generation is much as anticipated, with a general efficiency very close to the manufacturers specification (see example). For some situations, nearby buildings and trees shade part of the system, which reduces the PV output considerably. A different PV module subdivision and inverter strategy would have been less vulnerable to shading. For a full year, May 2001 to May 2002, the PV system delivered about 7200 kWh to the building, this result is corrected for lost energy during a short period of system malfunction.

The theoretically maximum generation should have been about 9400 kWh with the solar radiation registered for the monitoring period. The system overall efficiency, or performance ratio, was therefore about 75%. The losses are due to the shading at the site, the inverter configuration which is sensitive to shading, and lower efficiency at low solar intensity, which at this latitude is more pronounced. The efficiency compares well with results from other measured grid-connected systems (Ransome and Wohlgemuth, 2001).

The highest irradiation on the façade was measured at near 800 W/m² in March. Later in the year, the higher sun altitude results in a more oblique incidence angle on the PV cells. An example of monitoring results is shown below.

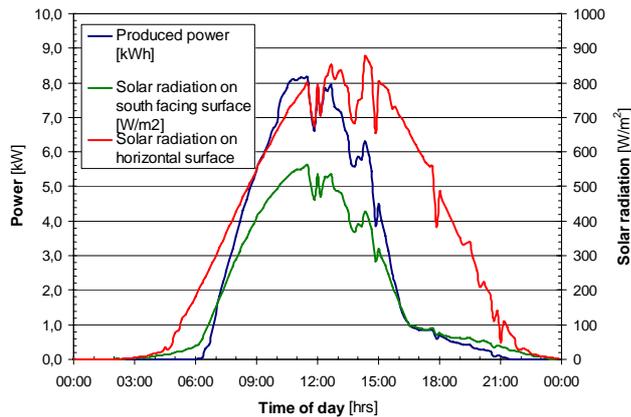


Figure 3. PV generation versus solar radiation for June 23 – 2001. The curves show measured data for the PV wall. On June 23, the solar radiation on the vertical south facing facade was 550 Watt/m² at 12:00 am. For the 100 m² PV wall the solar radiation was 55 000 Watt (55 kW). The measured power was 8 kW, which indicates that around 15 % of the solar radiation was transformed into electricity.

6.2 Thermal winter gains

The increased cavity temperature over the external temperature in the heating season gives an indication of the heating demand reduction achieved by the Solar Skin buffering and solar gains. The total heating energy saved was calculated to be 7-8 %, using a computer simulation program that takes into consideration the overall thermal balance of the whole building. The prototype building was very leaky for infiltration of outside air during windy periods. The savings here due to the new façade could not be taken into account in the calculations, as the improvement in air tightness could not be measured.

6.3 Summer conditions

A pre-construction study of the cavity performance (Aschehoug & al., 2000) showed that the best cooling strategy for summer conditions is to keep office doors open to the north side corridor and draw cold air from the corridor windows, using the solar façade cavity as an exhaust stack. The occupant survey shows, however, that some of the occupants at the top (4th) floor do experience periods of overheating in the summer. A closer investigation has revealed that under unfavourable combinations of high solar radiation, high outdoor temperature, and certain wind directions, the air flow in the cavity is reversed, resulting in the top floor offices receiving hot cavity air through the windows. A revised venting control strategy will be implemented to improve the summer conditions.

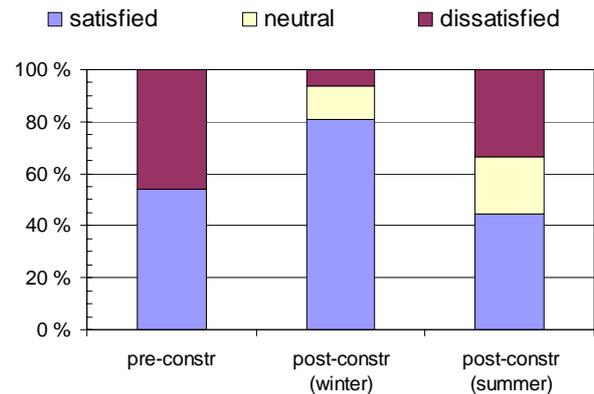


Figure 4. Bar diagram from last questionnaire survey.

7. CONCLUSIONS

The monitoring of the BP Solar Skin prototype has shown that the performance of the PV system compares well with other grid-coupled PV systems. The output would be slightly higher with a different and more costly system with more inverters. The heating energy reductions are, at 7-8%, not very high, but this figure was calculated without taken into account the effect of reduced infiltration. The occupants at the top floor experience periods of overheating in summer, due to reversed air flow under certain wind conditions.

8. ACKNOWLEDGEMENT

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REFERENCES

- Aschehoug, Ø., Hestnes, A.G., Matusiak, B., Lien, A.G., Stang, J., & D. Bell (2002): BP Amoco Solar Skin – A Double Façade With PV. *Proceedings of EuroSun 2000*, Copenhagen.
- Ransome, S. & J. Wohlgemuth (2001): Analysis of Measured kWh/kWp From Grid Ties Systems – Modelling Different Technologies Worldwide With Real Data. *17th European Photovoltaic Solar Energy Conference*, October 2001, Munich.
- Aschehoug, Ø. & A. Wyckmans (2003): BP Solar Skin – Occupant surveys before and after the construction of prototype. SINTEF Report, Trondheim 2003.