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Integration of Renewable Energy in the Built Environment (Electricity, Heating and Cooling)

Colored solar façades for buildings

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Abstract

Solar energy is a prime way to reach net zero energy buildings. Addressing buildings' energy needs is a priority because buildings are the largest demander of energy (followed by industry then transport). However, harvesting energy from solar farms, implies covering large areas with standard black or blue solar modules, which is generally not well accepted by the stakeholders. If architectural coherence is to be preserved, building envelopes cannot simply be covered with black panels with visible cells and contact bars. Today, panels of different colors are available to integrate solar energy smoothly into the built environment. However, while a choice of colors is good news for architecture, it should not cause excessive energy losses.
The Kromatix panels presented in this paper are covered by glass that combines effects of diffuse surfaces and interference filters. With a minimal loss of efficiency, these panels pave the way to new considerations in solar architecture.

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Keywords: Colors; Solar Energy; Integaration; BIPV; BIST

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1. Introduction

The acceptance of solar energy systems as integrated elements of the building's envelope is mainly limited by aesthetic considerations. They are often considered as technical components to be hidden and confined to roof-top applications. Architects require solutions that better integrate solar energy as building element components. One aspect of importance is the color of panels [1].

Multilayered interference filters can produce a colored reflection, hiding the active components, while transmitting the non-reflected radiation entirely to the absorber [2], [3]. This stands in contrast to pigment based coloring, which absorbs radiation and does not withstand degradation over time

When such colored glass replaces the conventional front glass of both PV and thermal solar panels, architectural integration of solar panels into glazed building façades becomes an attractive choice [3].

While a certain amount of freedom in selecting a color would be desirable, the colored appearance should not cause excessive energy losses and angular stability [2], [3]. The challenge lies in finding the best combination of material choice and layer thicknesses [4].

For the panels presented in this paper, a diffusive surface treatment has been applied on the outer surface of colored laminated glazing. The etching treatment has been applied in order to create diffuse light transmittance, which reinforces the masking effect of the colored filter [5] and prevents glare effects, which can be an obstacle for solar energy integration on buildings. The matt treatment replaces the specular reflection, usual with glasses, by a diffuse reflection. The development is presented in this paper.

2. Gloss reduction by satinated front surface

Etching on the outer surface of panels (the one exposed to the sun) provides a diffuse reflection to reinforce the masking effect of the technical parts of the solar device and to prevent glare effects.

Figure 1 b) presents SEM pictures of glass surfaces structured in the EPFL Solar Energy and Building Physics Laboratory. In the first case, the surface is relatively smooth and presents some micro-scale protrusions and furrows arising from the junction of nano-holes which are present on the entire surface. In the second case, the surface features a much rougher structure and is densely covered with a structure resembling pyramids. These pyramids have a height of around 10 µm, are defined by different types of polygons as their base area, whose dimensions are often around 100 µm to 120 µm and who have pronounced nano-structured side walls. The measured gain in solar transmittance can then be explained by anti-reflective properties resulting from micro-scale patterning in combination with a nano-scale roughness modification.

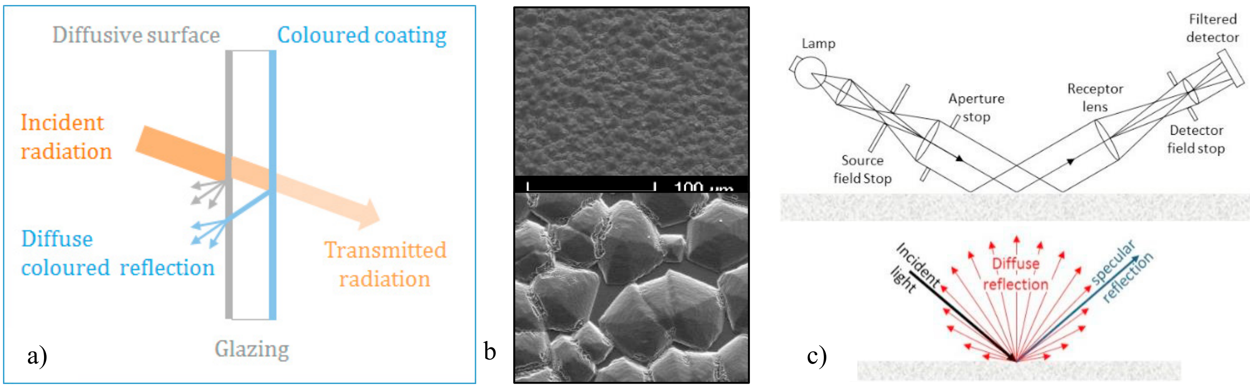

Fig. 1. a) Scheme of the glass with the diffusive surface and the colored coating.
b) SEM pictures of acid etched structures from the Laboratory of the LESO-PB.
c) Scheme of a gloss meter, diffuse vs specular reflection.

The etching also presents the advantage to create mat surfaces often desired by architects and to prevent glare effects. We used a Glossmeter at 60° (Fig 1 c) in order to measure the gloss index of availableindustrial solar panels. The gloss index of a c-Si PV panel is 90GU, about 120GU with thin film PV cells and 160GU for thermal collectors. Higher than 70GU is considered as a high gloss. With the Kromatix glass presented here, the gloss index becomes lower than 6GU for PV and lower than 14GU for thermal. An index below 10GU is considered as a low gloss index.

3. Flash test Modules

PV modules using back contact cells have been tested by the SUPSI in Switzerland. Standard black panels have a power rating of 300 Wp. Figure 2 shows the results of flash tests from a blue design and Figure 3 shows results from an orange design using Kromatix solutions. By replacing the standard solar glass with satinated glass with a thin film interference filter, the nominal power becomes about 280 Wp for the blue color and about 285 Wp for the orange (flashed under 1000 W/m^2 and at 25°C).

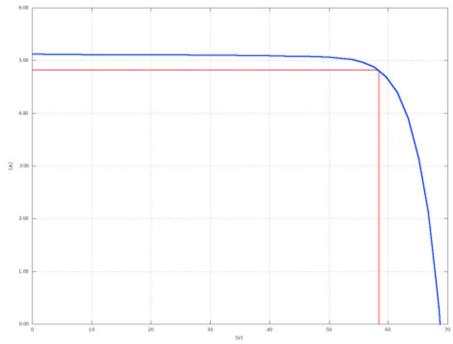

Fig. 3. Results of the blue flash test. Pmax: 281.33W, Vmp: 58.44V, Imp: 4.814A, Voc: 68.75V, Isc: 5.122A, Fill factor: 79.9%, Module efficiency: 17.3%

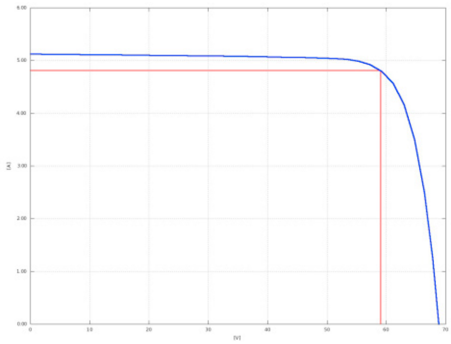

Fig. 2. Results of the orange flash test. Pmax: 284.10W, Vmp: 59.09V, Imp: 4.808A, Voc: 68.85V, Isc: 5.122A, Fill factor: 80.6%, Module efficiency: 17.4%

4. Building integration

In BIPV/BIST (Building Integrated PhotoVoltaics/Building Integrated Solar Thermal collector) the main key word is flexibility, especially for roofs and second skins. Active or non-active panels, small or large pieces have to be available with the same appearance and have to cover all surfaces.

The colored coatings are designed to be tempered and are produced as stock sheets (~3.2x2.2m). The standard thicknesses are 3.2mm and 4mm. But the production process can produce thicker glasses.

The glass passed tests in the climatic chamber of the EPFL-IMT laboratory in Switzerland. These tests prove that there is no visible degradation of colors with time. Colored glass submitted by different PV manufacturers passed furthermore the TUV or SUPSI certifications with success. IFT Rosenheim performed successful tempering tests and optical measurements. The tempering is usually made after the coating, proving the high resistance of the colored coating. The life time of the colored modules is the same as that of a standard module because it is mainly limited by the active components of modules (cells and sealant).

Figure 4 presents possible variations for the mounting of solar systems glued behind a colored laminated glazing. All details like the hangers, the overlap wings, the seals can be tailored to the wishes of the architect, to the type of buildings, the local conditions of the country, block, etc.

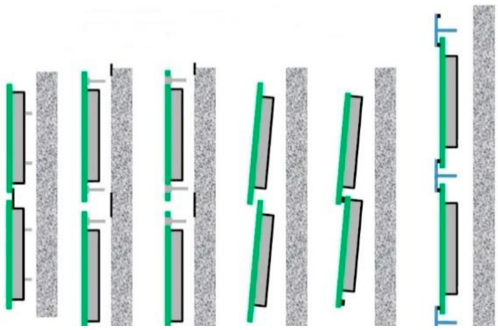

Fig. 4 : Possible variations for the mounting of solar systems glued behind a coloured laminated glazing with some examples of adaptation to large buildings with glass facades and ventilated façade.

Recent implementation on different buildings gives very promising values and a good acceptance from visitors. The Kohlesilo project is a renovated building with PV integrated on the roof and façades. The FESTO project is a flat roof building. The Copenhagen International School is currently one of the largest BIPV projects where complete façades are covered with solar modules.

4.1. Kohlesilo

The former coal silo in the Gundeldinger Feld in Basel was remodeled and now offers space for offices, conference rooms and a circus school. On the facades and the roof a building integrated PV system with colored modules was installed. To increase the self-consumption of electricity generated on site and to relieve the public grid, used lithium-ion batteries from a mobile application are used as Second Life battery energy storage [6].

Mono c-Si framed standard-size modules are integrated in the roof. Colors are black, green, blue, grey and gold. Custom-sized frameless glass-glass modules are installed on the south façade in grey, blue, gold and green color. The total surface of modules is 126 m^2 and represents an installed power of 15.7 kWp (Fig. 5). The north façade is covered by 40 m^2 of gold elements.

Type of pane	comparison	kWh/m^2
Black modules	Reference (100%)	14.6
Green modules	84%	12.3
Blue modules	80%	11.7
Grey modules	76%	11.1
Gold modules	76%	11.1

Table 1. Specific yield of colored PV modules on the roof for June 2016.

Fig. 5. The Kohlesilo in Basel. South façade with (from the left to the right) grey, blue, gold and green colour (11.3m^2 for each colours). The roof is a patchwork of black standard modules, grey, blue, gold and green coloured modules (total 81.7m^2). The north facade is not visible but represents 33.1m^2.

A first evaluation was made in order to compare the impact of the various colors on the yield. The black panels are compared to colored modules on the roof for June 2016. Results are presented in terms of specific monthly yields of the colored PV modules (Table 2) [6].

This building is using mono crystalline silicon cells. The silver strings that connect cells are called busbars and are visible even with the Kromatix glasses. They can be covered by a black ribbon to produce a perfect homogeneity. Masking the busbars does not add hotspot but reduces the efficiency of cells by covering a thin part of them. Flash tests proved this masking represents about 7% of losses.

The difference of efficiency between black and colored modules can be noted as following: Green (91%), Blue (87%), Grey (83%) and Gold (83%).Between March 2016 and June 2016 about 2.8MWh were produced by the PV system.

The solar field on this building occupies 80 m^2 and produces the same amount of electricity as the flat roof of the closest building, fully covered with standard modules but using three times the floor surface.

4.2. FESTO

Mounted in 2015, the FESTO building is a flat roof with the grey color. The choice of Kromatix panels came for two reasons: aesthetics and the vicinity of an airport. The glare effect of standard PV panels is a big concern for pilots near airports. The matt surface solves this problem. Due to the kind of roof, modules can be walked on. The mounting system is invisible and the building geometry is respected with the use of non-active panels (dummies).

The 224 m^2 of panels represent an installed power of 33kWp. The monitoring from April 2015 to March 2016 is shown for each month (Table 3).

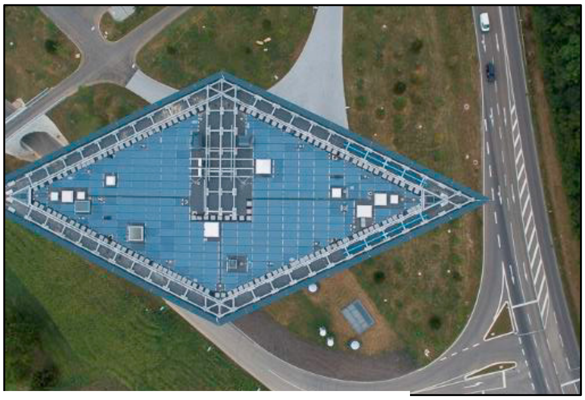

Fig. 6. FESTO roof seen from the sky.

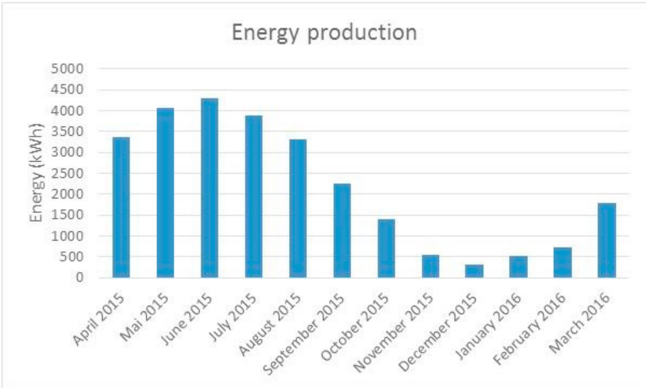

Table 2. Results of in situ monitoring of the FESTO roof during a year.

From these values we can calculate an energy yield of 26'531.8 kWh/year whereas the design value was 26'560.2 kWh/year. [7].

4.3. Copenhagen International School building

The facade is built as a “ventilated skin”. Each facade panel is approximately 70 x 70 cm, and is made of a front panel (PV) and a cassette behind (aluminum). The cassette gives the front panel a tilt of 4 degrees according to CIS architects’ wishes to animate the facade.

The outer walls of the CIS building are made of “Kingspan” (a sandwich construction of steel plates inside and outside, held together by foamed PUR).

The facade panels (PV front panel on a cassette) are mounted on the walls via a mounting structure custom designed for the CIS building. The mounting structure consists of several types of brackets and rails, and a number of flashing parts to produce attractive facade shifts at the mural crown, around window and door openings, at inner and outer corners, towards terrain/foundations, etc.

The entire facade system for the CIS building was comprehensively tested and proved in a series of qualification tests, performed in climate chambers and wind tunnels by accredited testing labs around Europe.

SolarLab takes part in the entire process, from project conception to final commissioning. In a close collaboration with the owner/developer and his architects and engineers, SolarLab developed a complete facade, accurately matching geometry and construction of the walls, to give the building an aesthetic and friendly expression.

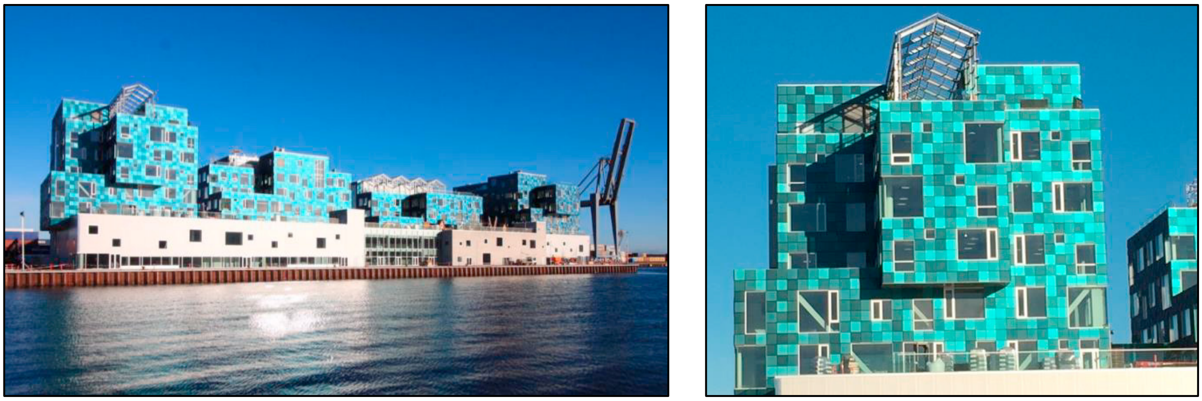

Fig. 7. Successful integration of PV panels on a façade of the Copenhagen International School.

The color and movement of the sea water find their response in the turquoise/lagoon-green color of the photovoltaic modules and the undulating movement of the light on the solar active façade elements.

The satinated front surface of the solar glass creates large-angle as well as small-angle light diffusion. In conditions of direct solar irradiation, the panels appear therefore differently when varying the angle of vision. The architect exploited this effect in order to create the lively appearance and dynamic expression of the solar façade in clear-sky conditions.

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