Final report

1. Project details

Project title	EnClose - Smart facades skins for new built and retrofit
File no.	64017-05218
Name of the funding scheme	EUDP-SOL
Project managing company / institution	SolarLab with support from Kuben Management
CVR number (central business register)	34720975
Project partners	SolarLab, DTU Fotonik, Aalborg University, Kuben Management
Submission date	June 30, 2021

2. Summary

The EnClose project has developed and demonstrated a competitive façade system with solar cells integrated, which can be applied both for new buildings as outer surfaces when retrofitting older buildings. This has been demonstrated on several buildings in the project periode. “The green house” on Grøndalsvej i Aarhus has been retrofitted with a new facade and has become even more green in the sense of color and self suppliens of electricity. It is the largest released project in the project period of EnClose with 2,350 sq.m of facade.

In the project period, several other facades have been realised with the same technology: Trifolium in Sydhavnen, Bornholms Hospital, a student accomodation in Amsterdam.

The project has from the start focused on facade systems for social housing, to show that BIPV facades are cost effective. Two projects have been realized. One is a gable in Tilst for the housing association Ringgården and the other on two smaller buildings in Kolding with 12 apartments where the whole building envelope will be covered with the cladding system.

The project in Kolding will be finished in 2022. For the project in Kolding there has been developed a system for applying facade integrated ventilations systems behind the cladding. The ventilation is a wall integrated system with in- and outlet in the wall.

The developed cladding system is a certified and CE labeled building material, which is delivered tailor made to every façade in terms of dimension, shape and mounting geometry as well as color and finish. The facade is delivered as a complete system with flashing parts and other fittings enabling the façade change, including the needed electrical system for connecting the PV to the electricity system of the building and monitoring

the system performance. The system is genuine BIPV, which as an outer surface of the building complies with fire resistance requirements, and further function as a weatherproof climatic shield for the building.

Danish summary

EnClose-projektet har udviklet og demonstreret et konkurrencedygtigt facadesystem med integrerede solceller, som kan anvendes både til nybyggeri og ved energirenovering af eksisterende bygninger. Dette er demonstreret på flere bygninger i projekt perioden. ”Det grønne hus” på Grøndalsvej i Århus er blevet eftermonteret en ny facade, og huset er blevet endnu mere grønt i farve og i graden af selvforsyning af elektricitet. Det er det største gennemførte facadeprojekt i projektperioden med en 2.350 kvm facade.

I projektperioden er flere andre facader blevet realiseret med samme teknologi: Trifolium i Sydhavnen, Bornholms Hospital, et kollegium i Amsterdam.

Projektet har fra starten fokuseret på facadesystemer til sociale boliger for at vise, at BIPV-facader er omkostningseffektive. To projekter er blevet realiseret i den kategori. Den ene er gavl i Tilst til boligforeningen Ringgården, og den anden er to mindre bygninger i Kolding med 12 lejligheder, hvor hele klimaskærmen dækkes med beklædningssystemet, facader som tag. Projektet i Kolding afsluttes i 2022, og til det projekt er der udviklet et system til anvendelse af facadeintegrerede ventilationssystemer bag beklædningen.

EnClose-facadesystemet er et certificeret og CE-mærket byggemateriale, der leveres skræddersyet til enhver facade med hensyn til dimension, form, monteringsgeometri, farve og finish. Facaden leveres som en komplet løsning med monteringssystem, der muliggør en fuldstændig facadeløsning, inklusive det nødvendige elektriske system for tilslutning af solcellerne til bygningens elnet og overvågning af systemets ydelse. Systemet er ægte BIPV, og facaden overholder brandkrav og fungerer som en vejrbestandig klimaskærm for bygningen.

3. Project objectives

The purpose of the EnClose project has been to develop and demonstrate a competitive façade system with solar cells integrated, which can be applied as a standardized building material for new buildings as outer surfaces, and as a new rainscreen cladding when energy renovating older buildings with additional insulation. The facade system is primarily targeting multi story houses.

To reach that point the cladding material has been developed, tested and demonstrated. The systems developed are to some extent standardized, and has been certified and CE-marked as a building material, which is delivered tailor made to every façade in terms of dimension, shape, mounting geometry, finish and color.

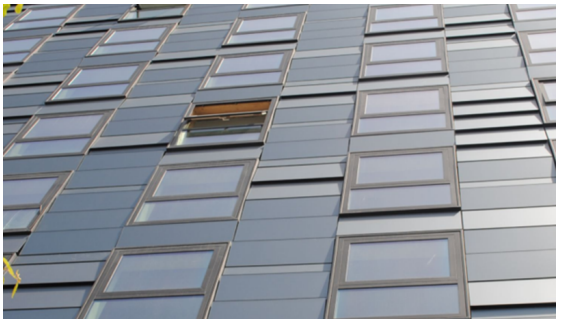
The facade is delivered as a complete system with flashing parts and other fittings enabling the façade change, and it will also include the needed electrical system for connecting the PV to the electricity system of the building. The system is genuine BIPV, which as an outer surface of the building complies with all fire resistance requirements, and further function as a weatherproof climatic shield for the building.

The major activities in the project have been:

- The solar panels have been tested.
- The system has been demonstrated at 3 buildings in Denmark and a fourth will be realized during 2021.
- Dissemination has taken place during the project periode and will continue.

4. Project implementation

The project has been very successful in demonstration of the technical concepts developed. Even though the demonstration in the beginning of the project period seemed difficult, and caused the need for extending the project duration, many facade demo projects were realized in the last part of the project periode, in Denmark and internationally, but more projects are in the pipeline. The gallery below shows some of the realized projects.



The Danish regime for building integrated photovoltaics does not favor this technology, and only reaches full utility if the building has high internal consumption of power, as for example private offices. A lot of obstacles have been made for public institutions even though they have a high consumption of power. The situation on the residential market is also miserable and the market has difficulties to mature.

If you are living in the central part of one of the larger Danish cities, you can probably look out on a skyline with new high raised buildings. Very few of them have integrated solar panels in the facades, even though they are highly exposed to the sun, and they also have a lot of new car charging points integrated in their parking areas. Denmark misses a very big opportunity for developing the BIPV industri together with the construction industry and their clients, due to this very restrictive policy on the market for BIPV.

These obstacles have been the main risk during the whole project periode; the question has been, will there be clients to use this technology?

Luckily there have been enough clients, and our obligations were fulfilled and globally the market is developing very fast. The Danish market has unfortunately not developed the same way; on the contrary. BIPV technology doesn't seem to have political attention.

Solar power as a building material for facades is a reality now, and there is a demand for good references, thorough experiences and documentation to be able to develop the industry. The EUDP-program luckily supports this development. Thank you.

It was foreseen that the market in Denmark would have developed in the favor of building facade-integrated BIPV solutions in the project periode, but the market has nearly closed down. It is mainly due to a lot of national regulations that do not favor solar energy on buildings, nor the sharing of power between buildings and this has further been exacerbated with new legislation that restricts BIPV on buildings owned by the Danish municipalities and regions.

The international market has opened up in the same period, and the demand is growing and several projects have been realized in the project periode, and the milestones have been realized.

5. Project results

The original intention of the project was to develop a unitized facade system which could fit into every building - retrofit as well as new build - and to develop tools for building designers, so they were able to design the facade by themselves. During the project periode it has been obvious that such a uniform facade system does not fit into the market, nor is there likely to be a demand for this kind of facade in the future.

The customers have different approaches and requirements, buildings are very different and the surrounding environments of the buildings are very different, so the facade system needs to be equally flexible and tailored to every project, to some degree, in order to obtain market acceptance and successfully fulfill the market requirements.

The electricity output is fractionally lower on a vertical facade than on an optimally positioned roof surface, but this is compensated for by the improved cooling and increased longevity of the PV technology, as well as the broader production profile when using multiple facades. Covering multiple facades with BiPV ensures that the production is more spread out over the day and that production improves in the spring and autumn. The energy producing facades furthermore frees up roof surfaces for rainwater management, green roofs and social activities, but at the same time it allows the building to retain the architecturally important material qualities of the angled roof surfaces.

The SolarLab production of facades have simultaneously become more efficient and local with a high degree of standardisation of subsystems, allowing customized products to be more efficiently produced in smaller numbers at competitive prices. The project experience also indicate a future potential for even more flexibility as well as higher efficiency and quality may be possible through the implementation of robots and development of new materials.

The customer demand is for a facade that solves a number of issues at the same time (aesthetic, technical and functional etc) and this requires a comprehensive facade system to ensure a successful facade integration on any building type. We have mostly seen solar panels on roofs and gables, with standardized solar products developed for roofs and field installation, and these do not work well on building facades (It

can be argued that they are also architectural eyesores on flat and slanted roofs where they deteriorate our build environment). The facade has to solve many other demands on top of its rainscreen function, most notably the aesthetic aspects are critical for user and market acceptance in the urban fabric.

The solutions realized in EnClose have been developed by SolarLab in a close dialogue and iterative process with clients, architects and other advisors, and the resulting cladding systems successfully fulfil all the demands and resolve all the constraints of the various buildings in the project.

This has resulted in a modular system providing broad design flexibility on a number of aspects while at the same time achieving a high degree of sub-system standardization. The system consists of 3 functional domains from the well proven fixation structures attaching the facade to the underlying building, the geometry layer where the panel dimension, build height, tilting, ventilation and fire protections is integrated, and finally the outer facade surface of custom made PV where visual aspects such as colors, finish, structure and glare can be tightly controlled and designed. This broad design freedom is loosely grouped in SolarLabs three main product families called ‘Skin’, ‘Shingle’ and ‘Sequin’, that allows for easy design of project specific combinations and variations to accommodate the clients desires and requirements.

The project has produced a design guide and a product description flyer to help communicate the unique value proposition and opportunities that a custom made BiPV facade provides to stakeholders, colleagues and clients.

Technology developed, tested and demonstrated

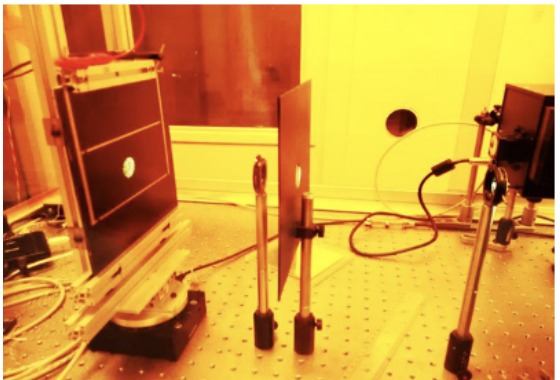
The BIPV façade system consists of three main functional elements; the façade cladding panels, a mounting structure holding the façade panels to the wall, and an electrical system evacuating the electrical energy produced by the solar panels. The EnClose project has successfully developed and demonstrated technology for all three elements, described in the following

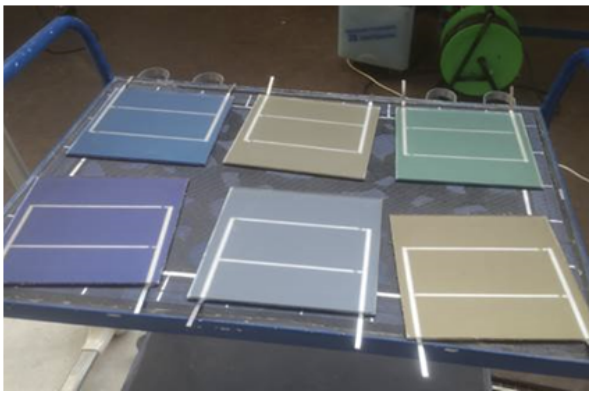
A key component in the façade cladding panel is the laminated photovoltaic module, with the colored and textured or satinated front glass. The PV panel laminate has been tested comprehensively, in laboratory tests as well as under real life conditions.

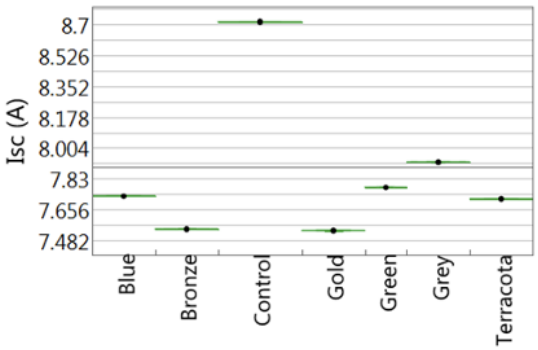
The laboratory testing focused on three parameters: a) describing the optical parameters and characteristics of the front glass, b) characterizing the power performance and efficiency of the photovoltaic panel, and c) demonstrating the physical strength and electrical safety of the PV laminate.

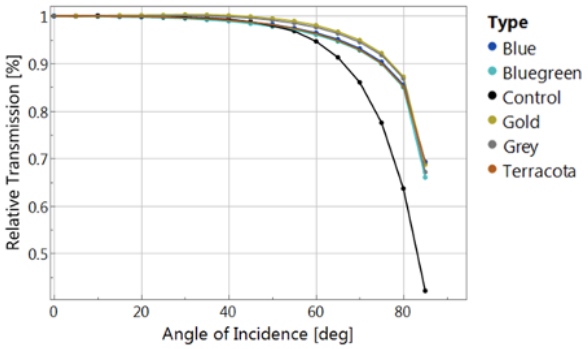
For this, a large number of very different tests were performed at and by DTU Fotonics, some of which were to characterize:

- Light transmittance and transparency of the structurally color coated front glass,
- Angular dependency of transmittance.
- Glare and reflections
- Resistance to extreme high and extreme low temperatures and temperature cycles.
- High humidity, deep freeze, and fast shifting between
- Resistance to accumulated UV radiation received by the panel over +30 years life







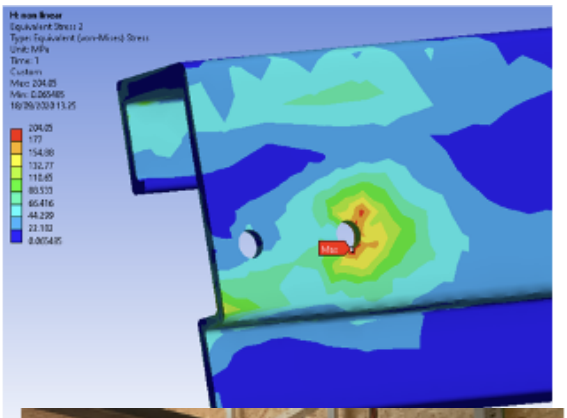


The results of the laboratory tests are described in detail in the scientific papers, attached to this report.

The PV laminate is held in place by a metallic structure, giving size and shape to the façade cladding panel. Several types have been developed during the course of the EnClose project, from simple flat panels, to very artistically shaped panels, with tilted, angled, skew and all sorts of combinations.

To fasten the framing of the façade cladding panel, we have chosen a fairly common and well proven “clip on rail” mounting system, which offers a high flexibility in attaching to almost any type of back wall and building structure.

The combined façade cladding panel with its mounting structure, and fixed to a solid back wall, has been designed, engineered and tested to withstand all common load conditions and environmental conditions.



The strength of main design elements and assembly details has been defined together with their critical load cases, and proven by simulations in finite element calculations, followed by physical testing.

Due to Covid-19 restrictions on traveling, some tests were performed by and at SolarLab, while witnessed (via a web connection) and results verified by third parties, some international testing laboratories.

Other tests were performed by SolarLab directly on the building sites, where the EnClose demo projects were installed to ensure the integrity and strength of the underlying building structure.

Standardization of panels

Investigation for standardization needs for building-integrated photovoltaic (BIPV) products includes European Union (EU) and North America (Canada, U.S.). Firstly, BIPV modules have to fulfill the following photovoltaic (PV) module safety standards in order to be successfully exported to the EU and North America.

Region	Safety certification	Design qualification
Europe	EN/IEC 61730	EN/IEC 61215
North America	UL 1703 or UL 61730 (USA) ULC/ORD C1703 (Canada)	UL 61215

Even though there are some similarities between safety standards UL 1703, UL 61730 and European and International version EN/IEC 61730 (like fire safety testing) but fundamentally both testing will be needed for the EnClose product to be eligible not only in EU market but also in U.S. Read about the similarities and differences of these standards here (LINK). Some of the testing differences occur due electrical grid differences and national requirements differences. For Canada it is ULC/ORD C1703 PV standard.

As a construction product in EU the BIPV system has to comply with EU Construction Product Regulation (CPR) 305/2011 according to European Standard (EN) DS/EN 50583 where the fire testing is done in accordance with EN 13501 and mechanical resistance of the mounting system has to be designed according to Eurocode EN 1991 (plus national rules) to withstand the action on structures like wind, snow and other.

BIPV systems in the U.S. have to comply with the fire testing defined in UL 1703 (requirement for PV in California Building Code) whereas this standard refers to fire testing according to UL 790 for BIPV and UL 2703 for PV mounting system. Furthermore, A BIPV system has to comply with national and state rules if applicable. This is also important for the Canadian market where products certify to CAN/CSA standards. Also, each province in Canada has their own adoption of the Model Code and municipalities further can

regulate on building standards, where this can complicate the design of the mounting system due to various local requirements (different wind loads etc.).

For these reasons the EnClose BIPV system are being subjected to testing and certification at TÜV Rheinland, who will issue all the following certificates.

Terrestrial photovoltaic (PV) modules – Design qualification and type approval	
IEC 61215-1:2021	Test requirements
IEC 61215-1-1:2021	Special requirements for testing of crystalline silicon Photovoltaic (PV) modules
IEC 61215-2:2021	Test procedures
EN 61215-1:2016	Test requirements
EN 61215-1-1:2016	Special requirements for testing of crystalline silicon Photovoltaic (PV) modules
EN 61215-2:2017	Test procedures
Photovoltaic (PV) module safety qualification	
IEC 61730-1:2016	Requirements for construction
IEC 61730-2:2016	Requirements for testing
EN 61730-1:2018	Requirements for construction
EN 61730-2:2018	Requirements for testing
UL 61730-1:2017*	Requirements for construction
UL 61730-2:2017	Requirements for testing
IEC TS 62915:2018	Photovoltaic (PV) modules – Type approval, design and safety qualification retesting

The technology and the market

The technology has been successful due to a very high degree of design freedom that allows for seamless and invisible integration of high efficiency solar cells in a facade cladding with material qualities designed to compliment the architectural vision. Building owners and architects have been able to develop solutions together with SolarLab so the cladding fulfills their demands in respect to color, shine and reflection as well as panelisation, dimensions and mounting geometry.

The mounting system has been essential and provide a plethora of opportunities for articulation through shifting build heights or individually tilting the panels in different ways, and in this way created dynamic play in reflections and shadows as well as different colors and structures of the facade. Also the custom sizes of the panels has been an opportunity for harmonious integration of PV in the building's facades by submitting to its inherent modularity and sculpture.

The first large scale project, Copenhagen International School on the waterfront in the North harbour area of Copenhagen, with building integrated solar panels with structural colors glass panels, which also led to this

EUDP project, has been critical to opening the market internationally for this technology. A lot of projects have been realized and a lot of projects in the pipeline have required this SolarLabs other realised project as full scale proof-of-concepts to de-risk the integration of BiPV facades on other projects. The EnClose project and the test cases have been a critical cornerstone in the foundation to support broader implementation.

There has been developed a calculation tool that can be used to assess the profitability of solar cell facades. The calculation tool includes a number of variables, such as facade price pr. m2 with and without solar cells, the size of the plant, the plant's expected production of electricity, the electricity price, the life of the plant / facade, etc. In collaboration with the client, the size of the various variables can be agreed / adjusted. The size of the investment and the profitability of a façade with solar cells can on that basis be calculated and compared with alternative façade solutions without solar cells.

As a result With the

Dissemination

The project preliminary results have been disseminated at the Advanced Building Skins conference in Bern, december 2018 with a poster and a presentation.

During the whole project periode there has been a continuous direct dissemination to potential customers on the technology - developers, building owners, municipalities and regions, and a collaboration with Solar City Denmark has enhances this dissemination:

EnClose Catalog presents the results of the project through a number of specific buildings, where the technology has been used. The publication is in both Danish and English version, and made as a pdf for download and for printing, so that a smaller edition can be made for distribution if desired. The developed EnClose catalog will be presented in an online version.

Enclose video: both in Danish and English. Will be publicly available on YouTube. The video shows the facade system of Enclose on facades of new constructions and renovation projects.

Workshops for housing associations, construction parties, and investors:

- Theme meeting
- Webinar on BLOX
- Building Green

Several scientific publications have been made based on results from the project which are listed below:

Riedel, N., Santamaria Lancia, A. A., Amdemeskel, M. W., Thorsteinsson, S., Poulsen, P. B., Plag, F., Kröger, I., Slooff, L. H., Jansen, M. J., Carr, A. J., Manshanden, P., Bliss, M., Betts, T., Jauregui, I. P., Mayo, M. E., Balenzategui, J. L., Roldan, R., Kräling, U., Baarah, G., Benatto, G. A. D. R. (2018). Interlaboratory comparison of methodologies for measuring the angle of incidence dependence of solar cells. In Proceedings of the 35th European Photovoltaic Solar Energy Conference and Exhibition

Riedel, N., Thorseth, A., Santamaria Lancia, A. A., Thorsteinsson, S., Poulsen, P. B., Iandolo, B., Davidsen, R. S., & Benatto, G. A. D. R. (2018). Direct Beam and Diffuse Spectral Irradiance Measurements in a Nordic Country Analyzed With the Average Photon Energy Parameter. In Proceedings of 7th World Conference on Photovoltaic Energy Conversion IEEE.

Riedel, N, Santamaria Lancia, AA, Amdemeskel, MW, Plag, F, Kröger, I, Slooff, LH, Jansen, MJ, Carr, AJ, Manshanden, P, Bliss, M, Betts, T, Jauregui, IP, Mayo, ME, Balenzategui, JL, Roldan, R, Kräling, U, Baarah, G, Zirzow, D, Lee, K, King, B, Stein, J, Kedir, C, Watts, J, Sauer, K, Thorsteinsson, S, Poulsen, PB & Benatto, GADR, Incident Angle Modifier Round Robin Updates, 2019, Sound/Visual production (digital), Technical University of Denmark.

Riedel, N, Santamaria Lancia, AA, Amdemeskel, MW, Plag, F, Kröger, I, Slooff, LH, Jansen, MJ, Carr, AJ, Manshanden, P, Bliss, M, Betts, T, Jauregui, IP, Mayo, ME, Balenzategui, JL, Roldan, R, Kräling, U, Baarah, G, Zirzow, D, Lee, K, King, B, Stein, J, Kedir, C, Watts, J, Sauer, K, Thorsteinsson, S, Poulsen, PB & Benatto, GADR, Incident Angle Modifier Round Robin Updates, 2019, Sound/Visual production (digital), Technical University of Denmark.

Clasing, L., Blieske. U, Riedel, N, Calculation and validation of the short-circuit current with spectral and angular resolved measurement data for BIPV modules with colored glasses. To be published at EUPVSEC Sept 06-10 2021.

Presentation of the project results: Newsletters are sent out nationwide via email, and disseminated internationally via LinkedIn

The planned presentation of the technology and project results at the end conference in Copenhagen, had to be postponed due to the Covid 19 shutdown. We expect to be able to complete it by the fall of 2021, possibly as a webinar instead of a physical event, depending on the situation.

6. Utilisation of project results

The result of the project feeds directly into SolarLab and the development of facades systems with solar energy. The result is used to expand the market position internationally and nationally for SolarLab, and to strengthen and broaden the possibilities for facades with PV integrated. At the same time it has transferred knowledge to Kuben Management on building integrated photovoltaic in facades, and the potentials of their consumers. The results as well influence the research of AAU and DTU and their transfer of knowledge.

SolarLab has during the period of EnClose grown from 2 fully employed to 5 fully employed and made the company a Børsen Gazelle in 2020.The turnover is growing as well as the orders.The market is growing due to growing demand for sustainable and low carbon building materials. Certification of buildings (DGNB, Leed, Zero energy buildings,etc) demands also PV facades. It will only grow.

The EnClose has led to a lot of experience on facades and facade systems for buildings. Solar panels can be used with a wide variety as building skins and can fulfil the demands from clients and architects. This helps open up the market of the technology. The facade fulfils not only a demand of an energy producing facades that can support the development of carbon neutral buildings, but also the ability to create unique buildings by using different kinds of architectural expresens by the facade cladding. Shape, color, mounting system etc. can be variated endlessly. The market for standard products, as we have seen for the roof mounted solar panels, are yet not so obvious for products to facades.

The solar facades as well send clear messages of the building owner's climate responsibility, and the energy generated by the facade can constantly feed into the building's consumption of power. Ventilation, cooling and electric cars make solar facades relevant even in temperate latitudes.

So far the SolarLab facade systems has proven its ability on multi storey buildings, but on high-rise buildings fire risks are a challenge and the facade systems have to fulfil higher demands on fire safety.

The market of facade integrating solar panels is growing, and also in the heights of buildings, and led to several potential projects for high-rise buildings. A large mockup for the hospital RH Glostrup with a solution for large-scale retrofitting of the building facade has just been implemented on the building in Glostrup (June 2020) for evaluation. This solution can be a lighthouse for renovating hospitals and reachíng low energy performance and perfect indoor environment, if the newly Danish regulations on energy producing for regions and municipalities can be bent or altered in favor of a more sustainable agenda for their buildings.

The hospital RH Glostrup: A SolarLab facade-mockup for a section of the building.

Project conclusion and perspective

- *State the conclusions made in the project.*
- *What are the next steps for the developed technology?*
- *Put into perspective how the project results may influence future development*

The facade system developed by SolarLab in the EnClose project fulfils the requirements of a facade system in terms of lifespan and structural strength for multi storey buildings, and at the same time to provide sufficient design flexibility to accommodate the architectural requirement of a wide range of architectural styles and construction methods.

Based on the full facade “SP Fire 105” and the “Single Burning Item” fire tests performed in Norway and Denmark we have found that the existing technology will require further developments and testing to be certified for highrise dwellings internationally. This is a key area of focus for SolarLabs, that will urgently have to be resolved to ensure successful and widespread adaptation of BiPV.

The active part of the facades has been shown to provide excellent energy performance due to the use of structural coloring and high performing solar cells. The integration of optimizers has improved the performance of the facade and is key to a resilient, fault-tolerant and high performing BiPV facade even on complex building volumes.

A system for hidden wall integration of room ventilation has been explored as well, but still needs to be tested and demonstrated.

The facade has been pre qualified as a sustainable building material, but does not yet fulfill the demands and certification for tall buildings, and the LCA and EPD needs to be further fleshed out with additional data that has proved hard to extract from the relevant suppliers. This is however changing and we expect to be able to receive the information in the near future. These kinds of life cycle analyses and certifications are rather expensive and the scale of the demonstration done in EnClose has not yet allowed us to reach this level of documentation and certification.

It is essential to have this substantial and full documentation to build the solid LCA required by the market in the future and to prove the environmental value of facade integrated solar panels.

Likewise, the panels and the mounting system has to fulfil the demands for fire protection for facades for high-rise buildings. These buildings and their facades have a large potential for on-site energy generation, while the roofs are proportionally much too small to suffice for these kinds of buildings to meet regulatory energy-framework requirements.

7. Appendices

1. Scientific report on testing DTU Fotonik
2. https://solarlab.dk/
3. Standardization needs for BIPV: LINK