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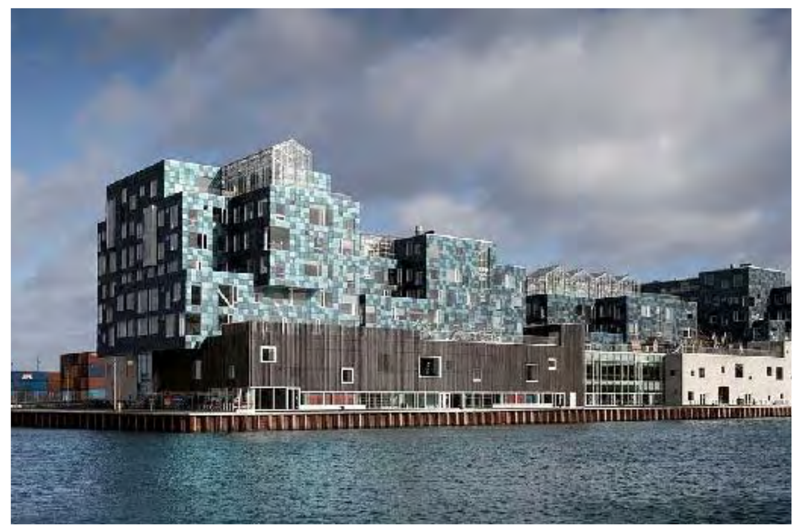
Successful

Building Integration of Photovoltaics

A Collection of International Projects




IEA-PVPS **Task 15**

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ISBN 978-3-906042-92-3 Successful Building Integration of Photovoltaics - A Collection of International Projects

Successful
Building-integration of Photovoltaics

A collection of International Projects

IEA-PVPS Task 15

0-01. International School, Copenhagen (DK)

IEA-PVPS TCP

What is IEA-PVPS TCP?
The International Energy Agency (IEA), founded in 1974, is an autonomous body within the framework of the Organization for Economic Cooperation and Development (OECD). The Technology Collaboration Programme (TCP) was created with a belief that the future of energy security and sustainability starts with global collaboration. The programme is made up of 6.000 experts across government, academia, and industry dedicated to advancing common research and the application of specific energy technologies.
The IEA Photovoltaic Power Systems Programme (IEA-PVPS) is one of the TCP's within the IEA and was established in 1993. The mission of the programme is to "enhance the international collaborative efforts which facilitate the role of photovoltaic solar energy as a cornerstone in the transition to sustainable energy systems." In order to achieve this, the Programme's participants have undertaken a variety of joint research projects in PV power systems applications. The overall programme is headed by an Executive Committee, comprised of one delegate from each country or organisation member, which designates distinct 'Tasks,' that may be research projects or activity areas.
The IEA-PVPS participating countries are Australia, Austria, Belgium, Canada, Chile, China, Denmark, Finland, France, Germany, Israel, Italy, Japan, Korea, Malaysia, Mexico, Morocco, the Netherlands, Norway, Portugal, South Africa, Spain, Sweden, Switzerland, Thailand, Turkey, and the United States of America. The European Commission, Solar Power Europe, the Smart Electric Power Alliance (SEPA), the Solar Energy Industries Association and the Cop- per Alliance are also members.

What is IEA-PVPS Task 15?
Building Integrated PV (BIPV) is seen as one of the five major tracks for large market penetration of PV, besides price decrease, efficiency improvement, lifespan, and electricity storage. IEA-PVPS Task 15 is an international collaboration to create an enabling framework and to accelerate the penetration of BIPV products in the global market of renewables and building envelope components, resulting in an equal playing field for BIPV products, Building Applied PV (BAPV) products and regular building envelope components, respecting mandatory, aesthetic, reliability and financial issues.
To reach this objective, an approach based on five key developments has been developed, focussed on growth from prototypes to large-scale producible and applicable products. The key developments are dissemination, business modelling, regulatory issues, environmental aspects, and research and development sites.
This Task contributes to the ambition of realizing zero energy buildings and built environments. The scope of this Task covers new and existing buildings, different PV technologies, different applications, as well as scale difference from single-family dwellings to large-scale BIPV application in offices and utility buildings.
The current members of IEA-PVPS Task 15 include: Austria, China, Belgium, Canada, Denmark, France, Germany, Italy, Japan, Korea, Norway, The Netherlands, Spain, Sweden and Switzerland.

Michiel Ritzen,
operating agent IEA-PVPS Task 15.

0-02. Solsmaragden Offices, Drammen (NO)

Foreword

To reach the goal of IEA PVPS Task 15, there was a need to collect and present unscalable BIPV projects.

A group of participants of IEA PVPS Task 15 (Sub task A) has analysed a selection of case studies in depth to pinpoint the possibilities and constraints encountered in completed BIPV projects. These case studies were selected to be good examples which are up-scalable and suitable for helping professionals in developing successful BIPV projects and in running the entire process.
The goal is to create a database that shows a number of selected case studies analysed in details, providing guidance for decision-makers (building owners, architects and project managers) to successfully apply BIPV in their project. A selection of case studies is published in this book.
The case studies are combined with input from participants involved in different phases of the BIPV projects. Their enthusiasm made it possible to get things done and to apply the BIPV in their projects.

In 2016, the first standard for BIPV systems (EN-50583 2:2016 : "Photovoltaics in buildings – Part 2: BIPV systems") was introduced. The definition is rather technical and many projects that are seen as BIPV are actually BAPV projects, according to the definitions used there.

We give both definitions here:
1. Building-Integrated Photovoltaic System BIPV system.
"*Photovoltaic systems are considered to be building-integrated, if the PV modules they utilize fulfil the criteria for BIPV modules as defined in EN 50583-1 and thus form a construction product providing a function as defined in the European Construction Product Regulation CPR 305/2011"*.

2. Building-Attached Photovoltaic System BAPV
"Building Attached Photovoltaic system - BAPV system. Photovoltaic systems are considered to be building attached, if the PV modules they utilize do not fulfil the criteria for BIPV modules as defined in EN 50583-1."

In this book, we have not applied these technical definitions as a limiting factor in the case studies.

We are pleased to share these ideas and opinions with you.
For further information, please consult the websites:
www.iea.org for getting general information about the International Energy Agency) and **www.iea-pvps.org** for getting specific information on the Photovoltaic Power Systems Programme.
The task 15 on-line database can be found at: **bipv.eurac.edu/en**.

0-03. Offices in Helsingborg (SE)

Content

What is it about ?

The general aim of the work conducted by the international group of experts involved in IEA-PVPS Task 15, was to give a clue of what makes a project successful with reference to the use of "BIPV" (see the foreword for the definition of BIPV).
At the same time, the intention was also to inspire those people who would like to change the standard pattern for conceiving buildings and to move forward sustainable buildings by using photovoltaic technologies.
This book shares the experience of people who thought of doing the same (and finally did!), as well as showing how buildings can look like when having a photovoltaic skin.

With this approach it is not relevant to seek for an overall methodological coherence, as the case studies collected in this work are very heterogeneous, and the paths the main stakeholders followed to reach the final goal are very diverse and the results variegated.
To select the best case studies and generate the necessary insight, an approach was built upon the research questions brought forward within the task 15 group, as described in the following.

In collecting the cases, the focus was the identification of the main stakeholders of selected projects in the countries participating in the research work of the Task. The common feature of such projects is that the national experts working in the research group had to have a direct connection with at least one of the main-stakeholders, to get the appropriate and necessary information.
The participants of the task selected what they assessed as lighthouse projects in their countries (based on open issues related on the use of photovoltaics in buildings) and conducted interviews with the main stakeholders, with specific reference to challenges they had to face.
The interview was structured in two main sections, Description and Business case. Under these sections specific issues were proposed. These were:

- Decision-making;
- Process;
- Building/system integration;
- Formal integration;
- Energy integration;
- Technical integration:
- Finance;
- Lessons learned.

A total of 25 case studies from 11 countries were collected, and they were classified in public buildings (5 cases); commercial buildings (12 case studies), residential buildings (8 case studies).
As a result of the investigation it is possible to summarize some short conclusions to outline the state of the art of the use of BIPV, and the necessary steps to be taken towards its further deployment.

Despite we all know that a shift towards energy self sufficient buildings is necessary, despite the important energy related regulations and directives, despite the availability of many technologies and components, despite the topic of the use of photovoltaics in buildings has been investigated for over 20 years now, the use of photovoltaic in buildings is still not an "out of the box" choice.

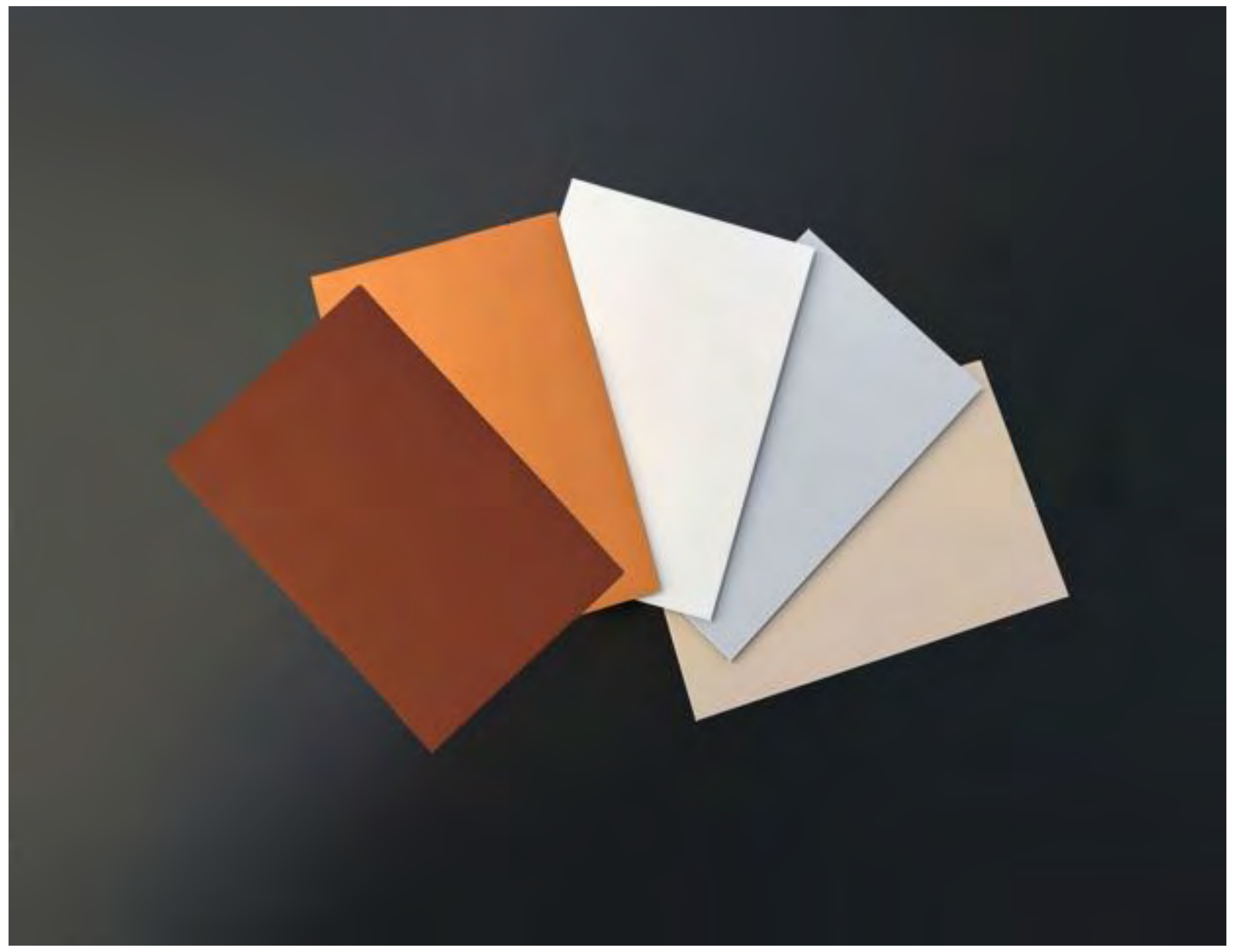
What we present is that BIPV is still not a standard way to conceive buildings.
The reasons why this is not standard are too many, but it is worth to mention some of them.
There is a strong need for an integrated design process as well as for innovative approval processes, and this is not guaranteed when following the usual pattern that goes from the idea of constructing a building to its realization, through all the steps that are needed in between.

There is still a gap between the building and the photovoltaic sector, and this condition translates into concrete difficulties for the architects when they have to choose appropriate photovoltaic components fitting to the existing regulations. In addition to this, the lack and complexity of standards and norms makes the use of BIPV in many cases very difficult.
The cost of photovoltaics, despite it is far lower than in the past, is still somehow a barrier when thinking of standard buildings (and standard prices) as references. Therefore, new reference (regional) cost parameters should be considered for taking into account the innovation. Maybe this could be done by creating reference pricing for different projects which have the goal of meeting specific/ambitious energy performances that can go beyond what is required by current regulations.

From the point of view of the evolution of the use of photovoltaics in buildings, from a formal, visual point of view, it is possible that a shift happened with regard to the past. If the pioneering cases of use of photovoltaics in buildings were strictly influenced by the aesthetics of photovoltaics suited for maximum efficiency, recent technological developments allow for a better design freedom. In particular, thanks to the low costs of PV (at the moment the lowest source of electric energy), it is possible to experiment with solutions that advantages the visual aspect even if the energy efficiency is penalized. This is the case of white or coloured modules, realized by adding an external layer to the photovoltaic glass surface, so as that the integration of photovoltaics is invisible (figure 0-05).

All the investigated cases are successful because of the strong willingness of some inspired stakeholders somehow involved in the realization of the building, who obstinately wanted to make a difference. Effective drivers for the use of BIPV are the large availability of variegated photovoltaic components and modules, as well as the knowledge of all the stakeholders involved in the process (from approval offices, to the client to the architect to the installers). Therefore it is relevant to continue with the applied research on BIPV components, and on education and training issues. Such effort is necessarily interdisciplinary and it is still an inspiring challenge for the next years.

Alessandra Scognamiglio, ENEL



0-04. Examples of palette of coloured films with innovative nanotechnologies available for customizing PV modules.

0-05. Apartment building façade, Boudry, Switzerland.

BIPV - it's not just a matter of building integration but also of cost-effectiveness!

What is the motivation behind a BIPV façade or roof? What are the technical challenges the architects and the planners have to overcome to design buildings with BIPV? What is the cost of a BIPV façade or a BIPV roof? These questions will be answered in this "book" by the presentation of BIPV case studies, stories, photos, technical details and drawings.
The presented case studies are distributed all over the planet, so it is difficult to compare them in an unambiguous way. Moreover, some data, especially those related to the price of materials and the price of manpower (BOS costs and labour costs) are very different for each country and even for each region. However, the collected information that is presented for each case study can be useful to understand the trend of BIPV and the evolution of BIPV facades and roofs.

The cost of a BIPV installation is not straightforward to assess, since it is strongly affected by variable factors such as the part of building skin under consideration (roof or façade), the construction site and the resulting boundary conditions for correct installation of the BIPV system, the characteristics of the local market, the legal and contextual conditions, the design, etc. that cannot be easily generalized. Especially when the BIPV design and installation are carried out simultaneously with other building interventions (e.g. the energy retrofit of a façade), it is possible to maximize the economic feasibility of the installation by reducing the extra costs caused by safety and practical requirements (scaffolding or safety railings, lifting by crane or mobile crane, etc.) and by applying administrative procedures to the entire building and not just to the BIPV system. For all these reasons, the cost and the prices indicated for each BIPV example in this book vary widely. In particular, among the 25 buildings, the costs range from 255 €/m^2 for an in-roof installation in the Netherlands up to 2,500 €/m^2 for the unique artistic façade deigned by Sarah Hall in 2010 for the Harbourfront Centre Theatre in Toronto (Canada). If we differentiate between roofs and façades, and we exclude the most expensive project due to its singularity, we obtain these figures: for a BIPV roof the prices range from about 250 €/m^2 to 660 €/m^2 without considering any government incentives or feed-in tariffs; for a BIPV façade installation, for which we can also identify two families, one related to rain-screen (back-rail system)

01-06. J&P Lougheed Arts Centre, Camrose (CA).

façades and the other related to curtain walls or atria (skylight overhang glazing), the cost ranges between 280 €/m² and 850 €/m² for the first family when a fully coloured module is used to hide the solar cells, and between 640 €/m² and 700 €/m² for the more expensive curtain wall installations.

Most of the prices take not only the cost of the façade/roof BIPV element into account but also the sub-structure and the thermal insulation used to guarantee that the building itself is energy-efficient. Moreover, also installation costs are often included, making the cost range between countries and projects even larger.
In this respect, it is interesting to see what happens when BIPV cladding is installed instead of regular cladding. The table on this page presents an overview of costs and benefits. The investment costs per m² are much higher for BIPV cladding but after 20 years (the lifespan of a commercial façade), the total cost difference between the two solutions can almost cover the cost of a new BIPV cladding system.

Assessing the real price of a BIPV component is not trivial, but it is certainly one of the keys to success in enlarging the market share of innovative technology. For this reason, the SET Plan "Declaration on Strategic Targets in the context of an Initiative for Global Leadership in Photovoltaics" indicates that the way to increase the BIPV market is to fix very ambitious cost reduction targets: 50% reduction of additional cost of BIPV components in 2020 and 75% reduction in 2030, with reference to the cost in 2015. The technology has proven to be an opportunity for making new buildings but also renovation projects more sustainable and also aesthetically pleasing. Now the goal is to make it even more cost-effective, taking the whole value-chain into account.

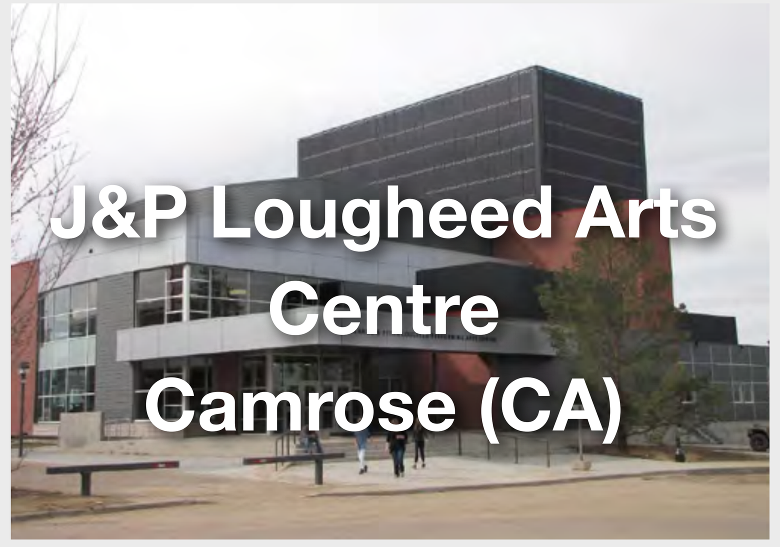
Francesco Frontini, SUPSI

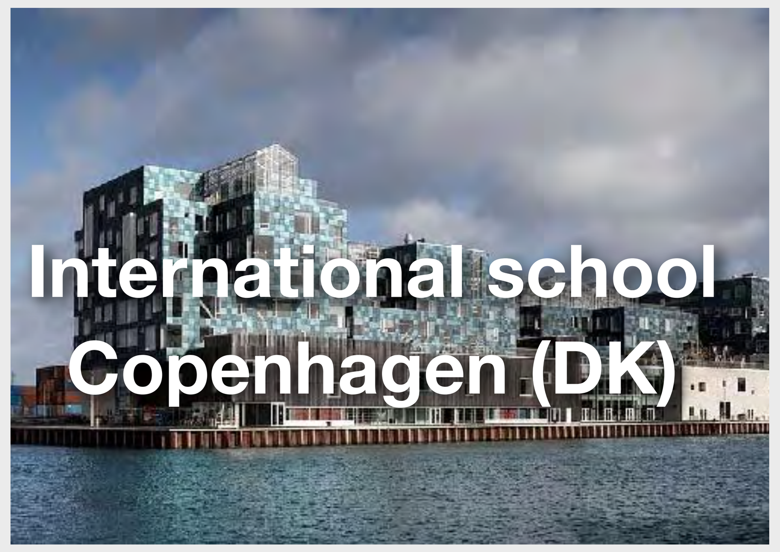
	Non-solar cladding	Solar cladding
Investment	€ 300/m²	€ 550/m²
Lifecycle	20 years	20 years
Cost per year	€ 15/m²	€ 27,5/m²
Energy generation	0 kWh	100 kWh
Energy profit	€ 0/year	> € 35/year
Electricity profit over 20 years	€ 0	> € 700
Total cost over 20 years	- € 300/m²	> € 150/m²

©Laurent QUITTRE, CEO of ISSOL

Foreword

What is it about ?





IEA-PVPS TCP

Picture Credits

Colophon

Public Buildings

J&P Lougheed Performing Arts Centre, Camrose (CA)

Project data			
Project type	New construction		
Building function	Performing Arts Centre		
Integration system	BIPV as façade cladding		
Location	4501 50 St, Camrose, Alberta		
Architect	Derek Sampson, BR2 Architecture	Year	2014
BIPV system data		**Producer data**	
PV modules	Conergy PH 250M BL triple-black	Producer	Conergy
Solar technology	Monocrystalline silicon	Address	80 Anson Road, 09-01, Singapore
Nominal power	120 kW AC (122 kW DC)	web	www.conergy.com
System size	488 modules, 882 m^2		
Module size	1652 x 994 mm		
Orientation	South, west, north and east		
Tilt	90° (vertical) façade	Author/editor	Konstantinos Kapsis, Véronique Delisle

J&P Lougheed Performing Arts Centre, Camrose (CA)

1-01. BIPV façade Camrose (CA).

Interview with Gordon Howell, Managing Principal, Howell-Mayhew Engineering and Michael Versteege, Manager, Energy Management & Sustainable Operations, University of Alberta.

Challenges
The idea was initiated in May 2013 while the building was already under construction. Thus, the PV size and layout were dictated by the size of the flytower on the building. We had only two months to design the PV system. First, we designed the DC part of the system so that the array construction could start as soon as possible. Then, we proceeded with the AC part of the system. As a result, the construction schedule was pushing the design process, which is not the preferable way for any project since so many key elements of a BIPV system are interrelated. During the design process, time should be allocated to simulate the hygro-thermal performance of the BIPV envelope. However, for this project there was no time for such analysis and the design decisions taken were simply based on experience. Integrating 488 standard off-the-shelf PV modules to seemingly fit the building and form its rainscreen had its challenges. The flashing between the modules was tailor-made. The purpose of the flashing was to prevent insects and birds from building nests in the insulation or between the modules and the insulation.
Initially, the installation contractor did not completely follow the string connections to the inverters as per the drawings. The inverters were single-phased whereas the building was on three phases. The incorrect wiring could have led to voltage imbalance in the building. At the end, we discussed the matter with the installation contractor and the wiring was corrected.

Also, the Canadian Electrical Code changed in the middle of the BIPV system construction. The new code required arc-fault protection for the inverters. The inverters initially selected did not have arc-fault protection. Knowing that the manufacturer would eventually discontinue the inverter model with no arc-fault protection, we had to choose new ones. The new inverters were of smaller capacity than originally planned, so the BIPV system ended up having a larger number of inverters.

Outcome
We did this project as a logical step toward meeting the University of Alberta greenhouse gas (GHG) emissions reduction plan objectives. As an added benefit, it allowed saving on operational costs. In 2017, the PV system generated 75 MWh. It reduced the annual electricity costs of the university by approximately $ 10,000 CAD (~€ 6,900) and emissions by more than 57 tons of CO_2 equivalent per year. Besides energy performance, this project was an opportunity to educate the university students and create awareness on solar PV technologies.

Decision-making
The GHG Emission Reduction Plan of the University of Alberta drove the decision. This was the third BIPV installation for the University of Alberta.

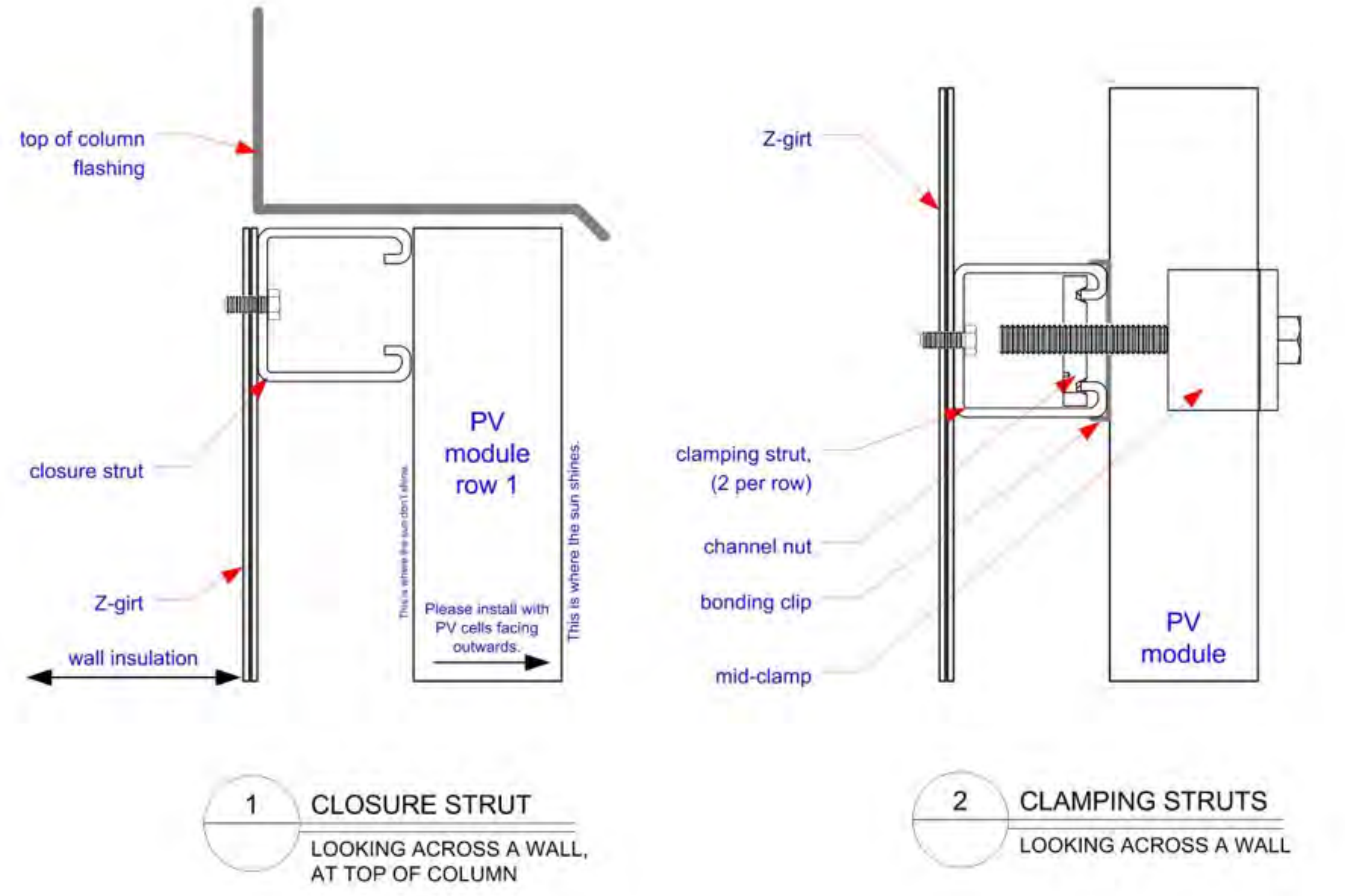
Process
As for many BIPV projects, the process involved several stakeholders. In this case the contractor for the realization of the building, had to enlarge the team when asked to deliver a BIPV system.
Building permits, Project planning, Structural design, Electrical design, Electrical permits and approvals & Post analyses of the electricity bills were the main areas to be covered through sub-contracting.
Clark Builders was the main contractor for the construction. Howell Mayhew Engineering (HME) was subcontracted to provide project planning, administration, and procurement. SolNorth Engineering delivered the structural design of the BIPV system while HME was responsible for the electrical design. Great Canadian Solar was responsible for obtaining the electrical permit and delivering the electrical installation of the BIPV system. HME obtained grid-connection approvals, commissioned the BIPV system and performed post analysis on the electricity bills.

1-02. West and south façades of the Jeanne and Peter Lougheed Performing Arts Centre.

1-03. *Installing the solar modules onto the south and west sides of the flytower. All four walls of the flytower were covered with BIPV for uniform appearance.*

1-04. *Racking system being installed on the west wall. The BIPV system serves as the building rain-screen and solar energy generator.*

1-05. *Mounted solar modules showing vertical Z-girts, insulation, horizontal Unistrut clamping rails, horizontal Unistrut sitting rail, horizontal flashing, vertical flashing and inter-strut electrical bonding.*



1-06. *Photovoltaic module attachments to racking and building.*

Formal integration
With an energy management program in place since 1975, the University of Alberta recognizes the need for GHG emission reduction to mitigate climate change. It believes that, as a university, it plays a leadership role in modelling the way to a sustainable future. Therefore, the university established the GHG Emission Reduction Plan in 2014 with the aim to reduce emissions to 17% below 2005 levels by 2020. To achieve this, several energy efficiency and renewable energy initiatives were implemented. This includes several buildings that integrate photovoltaics into the building skin such as the Jeanne & Peter Lougheed Performing Arts Centre.

Energy integration
Solar panels are installed on all four façades (south, west, east and north) of the theatre flytower of the performing arts centre. The BIPV system is grid-connected and supplies approximately 20% of the building's energy requirements. Almost all of the solar electricity generated is consumed instantaneously by the building.
The building also has a number of other important energy efficiency measures, including LED lighting for all the stage lighting and throughout the building. It is among the first few performing stages in the world to have LED stage lighting.
Upgraded insulation in the building envelope reduces energy requirements associated with heating and cooling. This benefit is increased further with the installation of a high-efficiency chiller and boiler. Underfloor air distribution is used to deliver the conditioned air at the floor level. This method allows for reduced HVAC equipment capacity and greater thermal comfort for the occupants without the need to condition the entire room.

Technical integration
The BIPV system had to meet the Canadian National Building Code as for all structures on buildings. Thus, all the necessary steps were taken (e.g. calculations for dead and environmental loads) to ensure that the installation met or surpassed the minimum code requirements.

Despite the lower solar energy generation potential on the north face, it was decided to install PV modules on all four sides of the 20-metre flytower in order to provide a uniform appearance. The BIPV system replaces the otherwise required rainscreen cladding. It was chosen over a conventional building-applied system mainly to reduce the capital cost of the building envelope. The BIPV system replaced the flytower cladding that would otherwise be needed and therefore, resulted in only slightly higher capital costs, which are offset by electricity bill savings.

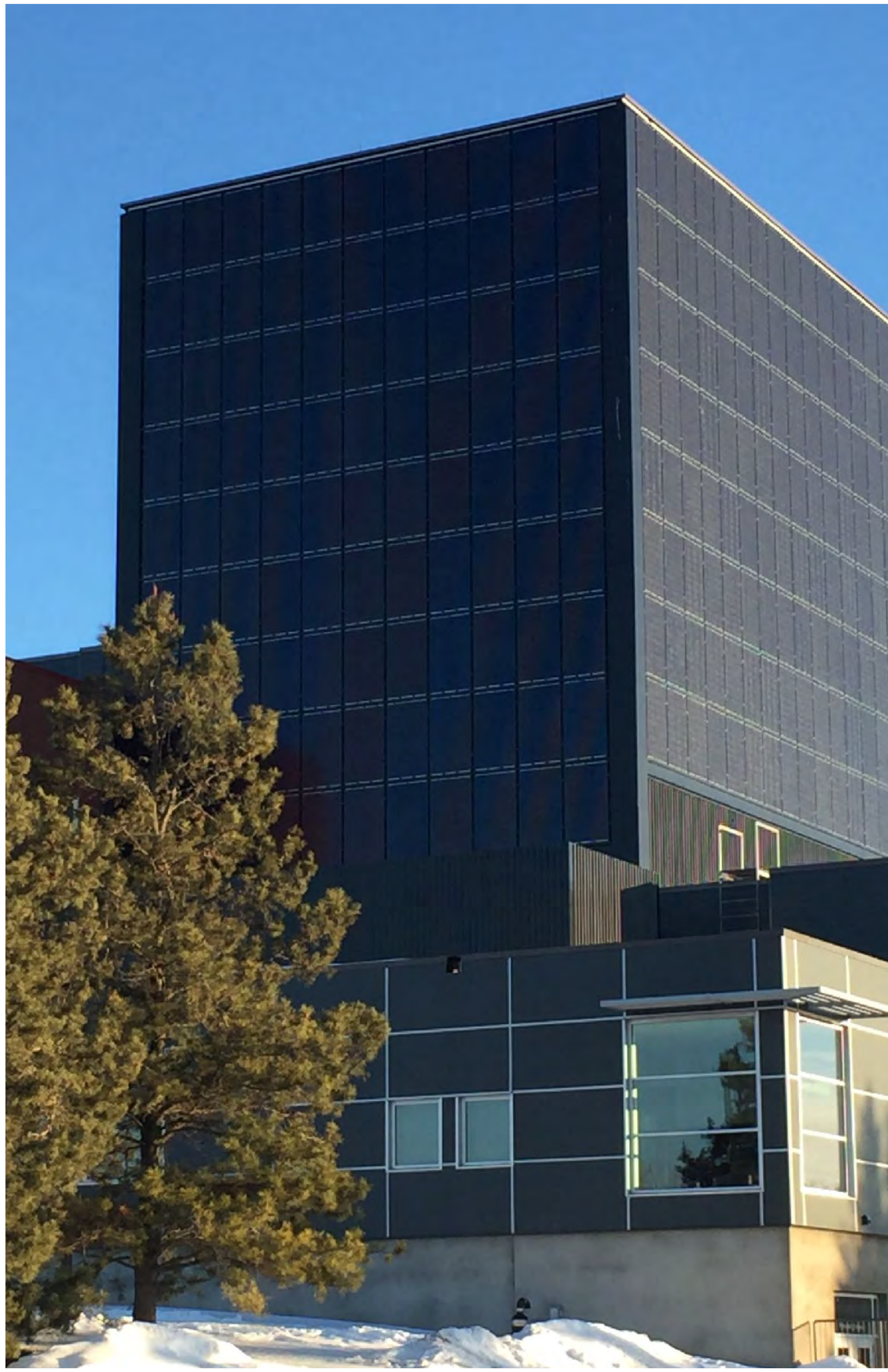
Vertical Z-girts and standard 3-metre Unistrut-type P1000T galvanized steel struts with aluminium clamps were used. Standard mill-finished racking clamps were powder-coated black so that they blend in with the colour of the modules. The DC cables run down the wall and into a gutter at the bottom, then over to the south side and into a conduit to the inverters located on the second floor roof. Flashing was installed between the modules to prevent intrusion by insects and birds.

1-07. West and south façades of the Jeanne and Peter Lougheed Performing Arts Centre.

Finance
At the time of construction, no capital-cost incentives for solar PV or premium feed-in tariffs were available to the university. The existing Class 43.2[1] accelerated capital cost allowance was not applicable to the University of Alberta as it does not pay taxes as a public institution. The BIPV system was financed through external borrowing. The investment is recovered by the savings in reduced use of grid electricity that result from the initiatives outlined in the university's energy management program called 'Envision' and by selling electricity back to the grid. The estimated payback time is 10-15 years, while the expected lifetime of the system is over 40 years.

Lessons learned
Designing a PV system with sub-arrays facing different directions was challenging because the sub-arrays are exposed to different irradiance levels throughout the day. As a result, the methods used to size the BIPV system's breakers and panel boards had to be adapted from standard electrical design practices. Another lesson learned from this project is that when designing a BIPV system, appropriate ventilation at the back of the PV array should be provided to reduce its operating temperature and improve the array efficiency. Allowing for ventilation should not compromise the building aesthetics, however, and care should be taken to ensure that the layers under the array remain invisible to the outside.

1) Under Class 43.2 in Schedule II of the Income Tax Regulations, certain capital costs of systems that produce energy by using renewable energy sources or fuels from waste, or conserve energy by using fuel more efficiently are eligible for accelerated capital cost allowance.


1-08. North and west BIPV façade.

Harbourfront Centre Theatre, Toronto (CA)

Project data			
Project type	Retrofit		
Building function	Performing Arts Centre		
Integration system	BIPV curtain wall incorporating artwork		
Location	Toronto		
Architect (glass)	Sarah Hall	Year	2010
BIPV system data		**Producer data**	
PV modules	Custom-made “triple-glazed” BIPV insulated	Producer	Glasmalerei Peteres Studios GmbH
Solar technology	Monocrystalline Silicon	Address	Am Hilligenbusch 23 - 27, D-33098 Paderborn
Nominal power	1.4 kW AC (1.56 kW DC)	web	www.glasmalerei.de
System size	10 modules, 21.5 m^2		
Module size	1549 x 1260 mm		
Orientation	73° Southwest		
Tilt	45° curtain wall (skylight)	Author/editor	Konstantinos Kapsis, Véronique Delisle

Harbourfront Centre Theatre, Toronto (CA)

2-01. Façade with BIPV glazing.

2.02. Harbourfront Centre, on the waterfront of Toronto, Ontario.

Interview with Livio Nichilo, CEO and Engineering Manager, Internat Energy Solutions Canada Inc.

Context

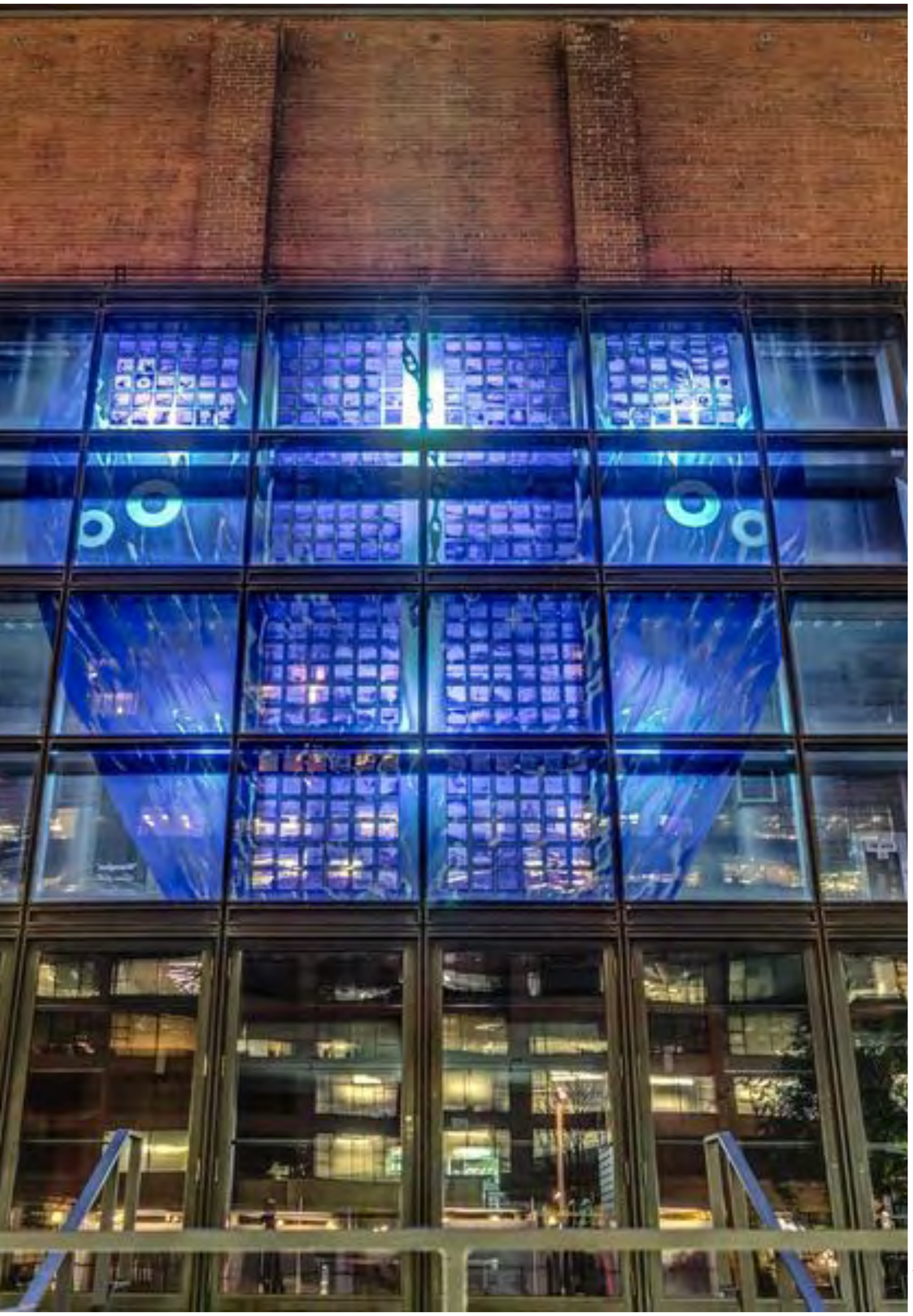
Harbourfront Centre Theatre is one of Canada's most popular tourist attractions – and one of the most unique and creative cultural centres in the world – drawing more than 17 million annual visitors and contributing millions of dollars to the local economy each year. Since 2005, Harbourfront Centre has been working on a series of projects that continue to transform Toronto's waterfront to Lake Ontario.
The Theatre was originally constructed in 1926 as an icehouse, where large blocks of ice intended for freight and cold storage were stored. In 1986, the space was repurposed into a versatile 416-seat performance venue. The theatre's unique design features include a sleek, three-storey curtain wall that encloses the entire northern, eastern and western sides of the theatre, providing acoustic insulation and thermal buffering, additional lobby space, and an aesthetic external finish that preserves the integrity of this historical building.

Challenges

At that time, the curtain wall surrounding the theatre was reaching the end of its lifetime and required replacement: there were issues with indoor temperature fluctuations due to low thermal resistance and high solar transmittance of the existing curtain wall system, acting as a greenhouse. This also resulted in condensation on the glass and significant humidity variations. Both temperature and humidity fluctuations started influencing negatively the performance equipment of the theatre. The centre was looking to replace the curtain wall with a new, high-performance system.

When we started looking into technologies to reduce solar heat gains (reflective glass, electrochromic glass or BIPV windows), a high-performance BIPV façade was an evident solution. If designed properly, BIPV can offset cooling, heating and lighting loads of the building while generating solar electricity, a feature that no other window technology can provide. However, this was the first time we were attempting to design and install a BIPV system (and one of the first installations in Canada) so there were some technical challenges along the way.

At the early stages of the design, we realized that there were no specific BIPV standards in place. In fact, even though the electrical performance of insulated glass units (IGUs) was warranted for 90% and 80% of the rated performance after 10 and 20 years, respectively, these were not certified by the Canadian Standard Association (CSA) since no standards existed at the time. In addition, CSA-approved inverters are generally larger than the inverter we needed. Finding and evaluating a reasonably priced, locally sourced, 1.5 kW inverter with monitoring capabilities, good technical support, and short delivery time was time consuming. Major delays occurred regarding manufacturing and shipping the IGU overseas. Delays also occurred because Toronto Hydro was unfamiliar with BIPV technologies, which caused confusion regarding system impacts and required assessments. This is why it is important to set the proper standards, codes and regulations to accommodate for a complex technology such as BIPV. It is the only way to reduce risk and accelerate the implementation of BIPV technologies in the built environment.



2-03. Watermark art installation as part of the west-facing façade of the theatre, backlit with LED lights at night.

Decision-making

In 2009, Bill Boyle, CEO of Toronto's Harbourfront Centre until 2014, was interested in incorporating new technologies into the Centre that reflected a sustainable outlook. At that time, the curtain wall surrounding the theatre was reaching the end of its lifetime and required replacement. A pre-feasibility study was assigned to IESC to evaluate the various façade technology options through Building Information Modelling (BIM).

The objectives of this project were to (i) replace the existing outdated curtain wall with an advanced performance one that will create a more comfortable and less energy-demanding indoor environment, (ii) mirror the sustainability commitments of the Centre and, (iii) create a narrative that links this historical building with the City of Toronto and its waterfront, through art.

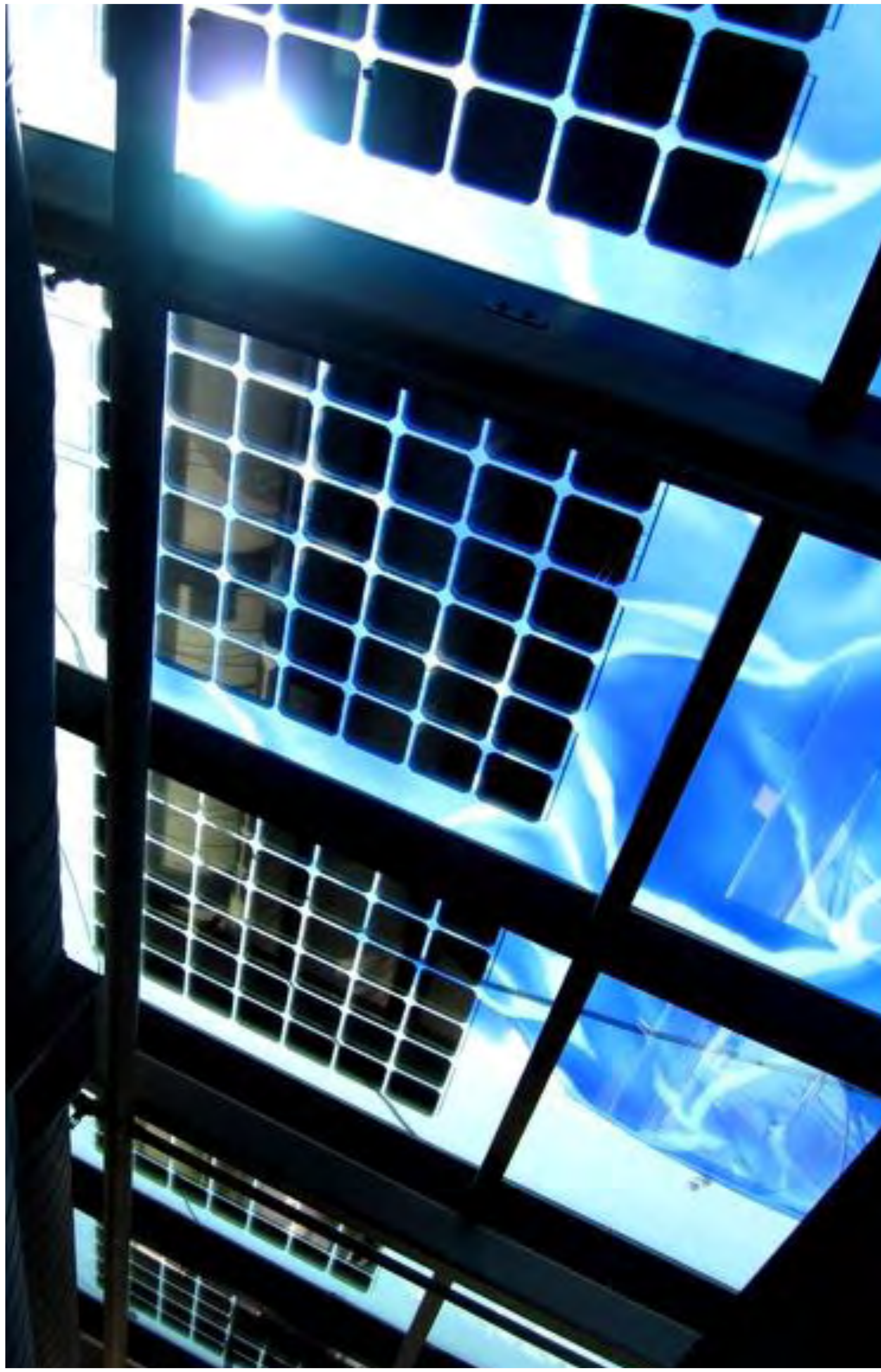
The pre-feasibility study indicated that a curtain wall system that integrates photovoltaic technologies and art could satisfy all objectives. However, as the proposed solution was a novel, custom-made technology demonstration, there was a price premium associated with it. In 2010, securing funding through private and public sectors as well as fundraising events made possible the realization of a retrofit project that seamlessly integrated BIPV and art on the façade of a historical building in Toronto.

Process

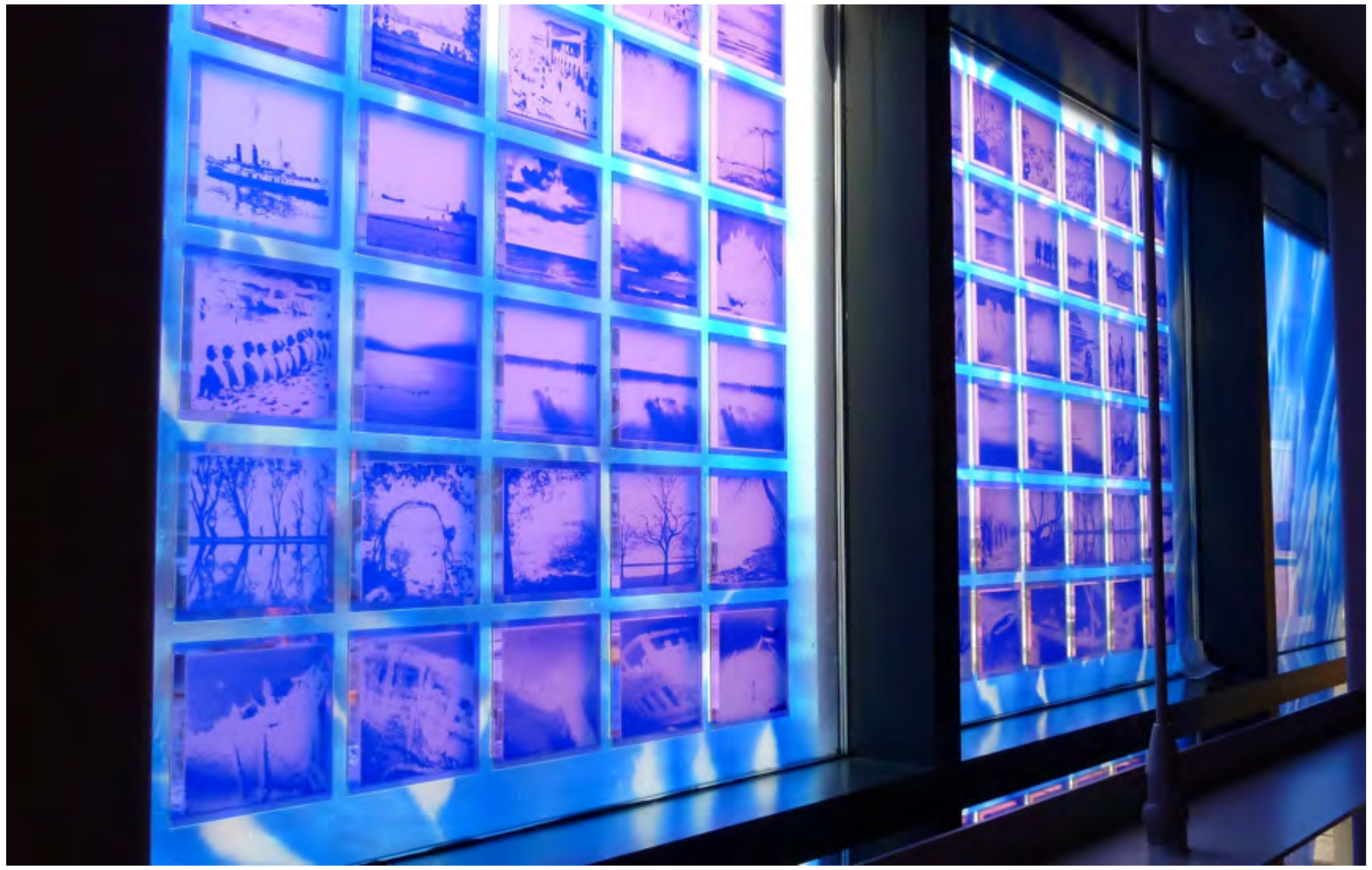
The pre-feasibility study was performed by IESC. The fundraising was carried out by the Harbourfront Centre. The project design, specifications and management were delivered by IESC. IESC and Fitzpatrick Electric prepared and submitted documents for electrical permit. The artwork was incorporated by Sarah Hall, and Glasmalerei Peters Studio. The BIPV skylights were integrated in the curtain wall by Faber Solariums that was also the main contractor for this project. The electrical installation and commissioning was completed by Fitzpatrick Electric.

Building / system integration
Integrating technology with art, Sarah Hall, a local Canadian artist, along with Glasmalerei Peters Studio in Germany, was able to create within the glazing, a permanent art piece called Watermark that wraps around the Theatre. A series of artistic images and a collection of 360 photographs, compellingly documenting the history of Lake Ontario, were permanently embedded into the glass envelope that now generates electricity during daylight hours and is backlit with programmable, colour-changing LED lights at night.
The artistic elements were created overseas with airbrushed, fired enamels sandblasted onto architectural glass. The photographic image gallery visible from within the building uses screen-printed photographs and dichroic glass. The transformation of the Harbourfront Centre Theatre provides a stunning example of how technology, a commitment to environmental sustainability and artistic creativity can be beautifully matched.

Energy integration
Ten customized BIPV insulated glass units were installed on the near-West facing skylight curtain wall of the Centre. The BIPV system is grid-connected and most of the electricity generated is consumed instantaneously by the building.
Besides the generation of 1500 kWh per year of solar electricity, the BIPV contributes to the reduction of the theatre's energy consumption: the effective optical and thermal properties were carefully selected through Building Information Modelling (BIM) simulations to reduce heat gains during summer, reduce heat losses during the winter and allow sufficient daylight into the lobby space throughout the year. Hence, the BIPV curtain wall reduces the theatre heating, cooling and lighting loads in addition to improving thermal and acoustic comfort. IESC estimated that the BIPV retrofit results in annual savings of 28 MWh of electricity (due to space cooling reductions) and 10,600 m^3 of natural gas (due to space heating reductions). These energy savings translate to a greenhouse gas emission reductions of approximately 25 tons of CO_2 equivalent per year.



2-04. Interior view of the west-facing BIPV skylight of the Harbourfront Centre Theatre incorporating Watermark, a permanent art installation.



2-05. A series of artistic images and a collection of 360 photographs are embedded.

2-06. View of the west façade.

2-07. Inside view. The pictures document the history of Lake Ontario.

2-08. Another view from the inside.

Technical integration
The BIPV system needs to meet the Canadian National Building Code as for all structures on buildings. Thus, all the necessary steps were taken (e.g. calculations for dead and environmental loads) to ensure that the retrofit meets or surpasses the Code. In addition, the installation was designed and installed to comply with the Electrical and Fire Code.

The ten 156 W_p BIPV modules are wired in series and connected to a Kaco 1502xi inverter. The wires run inside the curtain wall mullions, to be both protected by the elements and invisible. All BIPV system components, including the skylight windows, are accessible for maintenance, if required. Snow guards are installed toward the bottom of the roof to ensure pedestrian safety in case of sliding snow.

The inverter is located at level 3 of the theatre, approximately 3 m away from the BIPV installation. It is mounted on an aesthetically pleasing wooden board in order to be visually appealing for the visitors. Also, mounted on the board are the DC and AC disconnect devices required by the Electrical Safety Authority. For additional safety, an externally located AC disconnect was also installed as a requirement of Toronto Hydro. An optional Kaco watchDOG card was also implemented, allowing the performance monitoring of the system through a web-based portal. Finally, a net-metering system was applied, directly serving the building's load.

2-09. Sarah Hall.

2.10. East and north façades of the Harbourfront Centre Theatre.

Business case

Finance
No incentives from utilities were made available for the BIPV installation. However, funding was received from both the private and public sectors through the Toronto Atmospheric Fund, Toronto Sustainable Energies Fund, Canadian Heritage Fund and Enwave. In addition, Harbourfront Centre held fundraising events to help finance this building retrofit project. As the BIPV installation demonstrates the integration of sustainable technology and artwork, payback was not a core objective for this project.

Lessons learned
Designing and implementing a high-performance BIPV curtain wall system that integrates artwork is challenging. It requires the use of BIM tools to assess the impact of the BIPV system and the artwork on the building heating, cooling and lighting loads. It also requires strong coordination between the project manager, the structural engineer, the artist, the installer and the electrician.

The conventional linear design process does not work.

It requires concurrent engineering, an integrated design process where all parties comprehend the installation functions and project objectives and work in parallel. Finally, when the proper standards, codes and regulations are in place, the project timelines can be reduced by half.

2.11. West façade of the Harbourfront Centre Theatre incorporating a BIPV skylight.

Brynseng Primary School (NO)

Project data			
Project type	New construction		
Building function	School building		
Integration system	Glass façade		
Location	Brynsengfaret 10, 0667 Oslo		
Architect	Ida Hexeberg, HRTB Arkitekter	Year	2017
BIPV system data		**Producer data**	
PV modules	Issol CENIT 220-6112, 38 to 448 W_p.	Producer	Issol
Solar technology	Monocrystalline silicon, frameless	Address	ISSOL sa, Rue du Progrés, 18-4821 Dison (B)
Nominal power	166 kW_p	web	http://issol.eu
System size	656 modules, 1046 m^2		
Module size	26 different shapes, from (400 x 664) mm^2 to (2760 x 980) mm^2		
Orientation	South (185°)		
Tilt	90° vertical	Author/editor	Anne Gerd Imenes

Brynseng Primary School (NO)

3-01. BIPV façade at Brynseng.


3-02. Brynseng school depicted in its urban surroundings (from the planning stage).


3-03. Red coloured elements were added by the architect to break up the black façade.

Interview with Ms. Bodil Motzke, environmental advisor, and Ms. Magnhild Kallhovd, technical project manager, for the builder and owner Undervisningsbygg Oslo KF.

Ms. Bodil Motzke: We had already built around 20 schools according to the passive-house standard and needed a pilot to show the next step, i.e., a building that produces energy. I managed to sell the idea of testing BIPV in a nearly-zero energy (nZEB) pilot case to the management group of Undervisningsbygg, as part of our environmental strategy. The governmental education authority was positive about the project and mostly concerned with securing the functionality as a school, rather than whether a PV solution was chosen or not.

Ms. Magnhild Kallhovd: The city council has an ambition that public buildings in Oslo should be built as ‘plus-energy’-buildings. There will be more schools like this in future; not all may have solar cells but it is clearly the way to go. We wanted to use as much of the solar energy as possible in the school building. As the school is closed in summer, we chose to clothe the whole southern façade with PV instead of using a traditional rooftop system. This gives a lower, but more even energy production, over the year.

Ms. Bodil Motzke: Brynseng was chosen due to its location, with no shading in front of the south-facing façade and since there were several tall commercial buildings nearby. This meant that a ‘technical PV façade’ would be acceptable from an aesthetical point of view. In hindsight, the aesthetical concerns proved to be unfounded due to the high quality of building integration. With over 1000 m^2 of BIPV, this is one of the largest integrated PV façades in the country, which makes it a very innovative project.

Interviews with Ms. Bodil Motzke and Ms. Magnhild Kallhovd, performed by Mrs. Anne Gerd Imenes, Teknova AS, during the period 2016-2017.

3-04. Environmental advisor at Undervisningsbygg, Ms Bodil Motzke (l) and technical project manager Ms. Magnhild Kallhovd (r).

Decision making
The initiative to apply a PV system to the building was taken by the owner Undervisningsbygg Oslo KF, a property company owned by Oslo municipality with the responsibility to build and maintain school buildings in Oslo. The order was placed by the Education Department of Oslo municipality, which willl also be the rental user of the building. The final decision was made when financial support from the 'Energy-efficient buildings' program of the public financer Enova was approved in autumn 2014.

Process
The BIPV solution was proposed as an idea during the pre-project phase, which is a late stage in the planning process. The school building was already drawn up as a regular building without PV. However, new drawings were made and an application for financial support was sent to Enova. The PV elements were drawn on the façade as the roof area was not available. The architect desired an integrated architectural expression. At that stage, the involved parties did not know much about different technologies and what they could offer.

During the project, it became clear that the PV installation had to adhere to both glass façade standards (using safety glass), as well as electrical and fire safety requirements. The latter were quite unclear. The local grid company performed an inspection of electrical systems and concluded that a façade installer can mount and connect the PV modules, provided close collaboration with the responsible electrician, a safe-job-analysis, and a sufficiently insulated system with quick-release coupling were guaranteed. The installer had to be registered and deliver a compliance declaration for the design work according to the regulation on electrical low-voltage systems in Norway. Undervisningsbygg prepared operation and maintenance instructions explaining what needs to be taken into consideration with regards to safety.

The partners involved in the project were: The Educational Department in Oslo (placing the order and user of the building), Undervisningsbygg Oslo KF (builder and owner), NCC Norway (entrepreneur and project coordinator), HRTB Arkitekter (architect), Norconsult (advisor for energy and environment), Multiconsult (advisor for design simulation, purchase specifications and quality control of the BIPV façade), Issol (BIPV module supplier), Staticus (BIPV façade projecting and installation), and Steen Jørgensen (electrical services).

Building/system integration

Formal integration.

The school is designed for 840 pupils in years 1-7. It is a newbuild of around 11600 m^2 net area and six floors, with a large, multi-use sport hall at the upper level. The school is built on an old industrial site near the Alna river, with a railway and underground station close to the front entrance. The PV is integrated into the south-facing façade at the back of the building, covering 37 % of the school façade area. It is visible from afar, which gives it a demonstration value. Pupils and teachers can follow the power production and consumption in the building, which also gives a pedagogical dimension. A uniform 'non-technical' BIPV façade has been achieved using all-black modules and fastening brackets. All module formats were adapted to the façade to give a holistic architectural impression.

Energy integration.

As there is no clear regulation in Norway for the definition of nZEB, it was decided that the building should use 70 % less energy than the existing technical standard (TEK10), with net externally delivered energy below 40 kWh/m^2/yr. To achieve this, a range of energy solutions was implemented including natural lighting, heat pumps and 20 energy wells drilled 250 m deep into the ground. The energy consumption for heating and hot water is covered to 90% by the heat pump/ ground well system, whereas the PV system covers 25% of the electricity consumption. The estimated annual PV production is 105 MWh (633 kWh/kW_p). When the school is in use, all PV electricity is consumed. When it is empty during weekends or vacations, power is exported to the grid within the 'plus-customer' limit of 100 kW. Overall self-consumption is expected to be 80-100 %.

Technological integration.

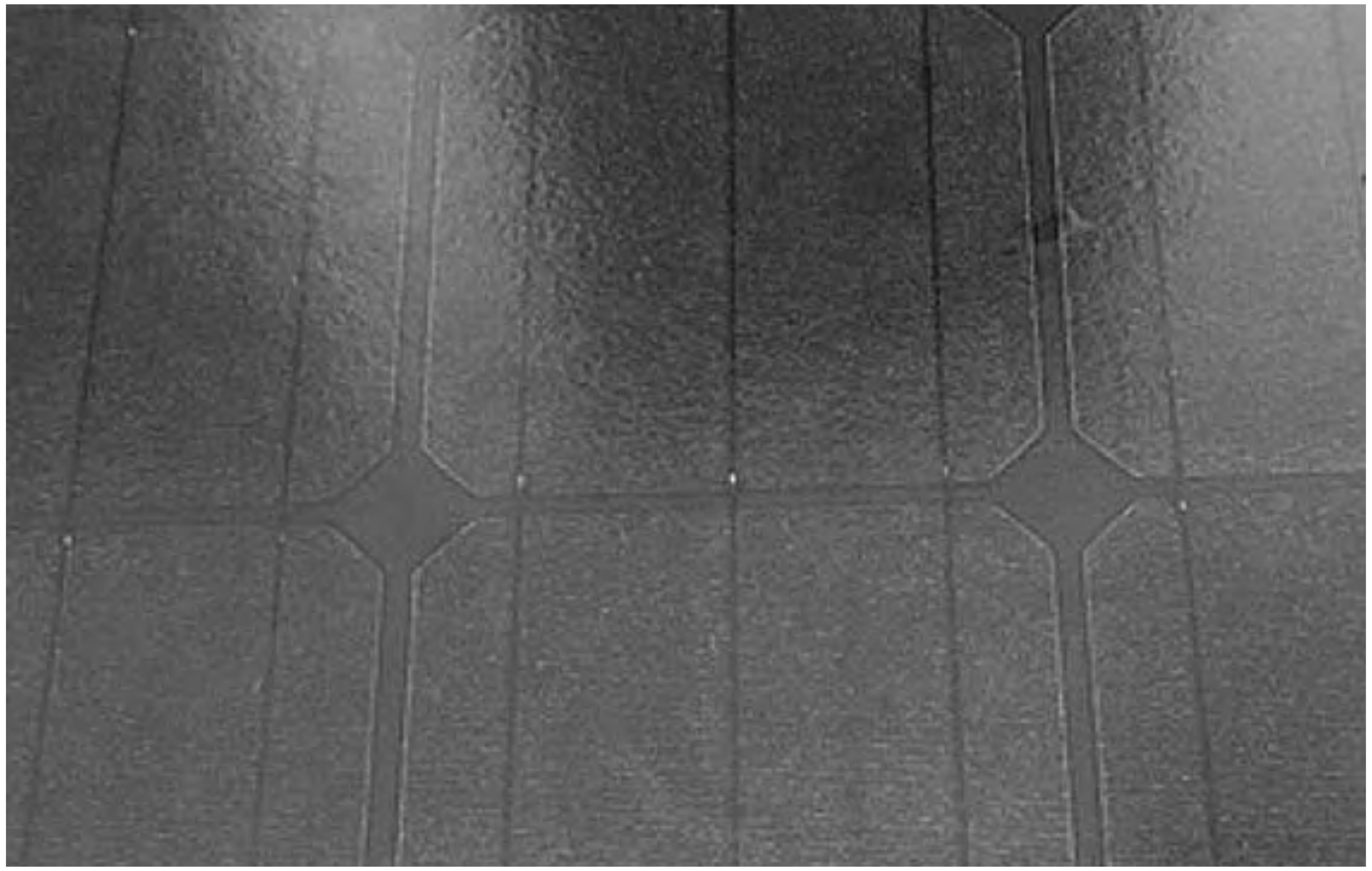
The modules are custom-made in 26 different sizes adapted to the façade area. The frameless modules consist of standard black mono-crystalline silicon solar cells with black-painted metal wires and busbars, and 4 mm building-approved safety glass at the front and back. The modules are mounted as back-ventilated cladding with waterproof insulation at the back, which will dry out in case of moisture intrusion. The BIPV façade fastening method was especially developed for the project by ISSOL and installed by Staticus. They used standard but deeper brackets for façade glass mounting, fastened to the battens of the climate wall, with PV modules hooked into the brackets. The DC cabling outside is hidden behind the BIPV modules. Inverters are placed inside, distributed in several electrical service rooms to reduce DC cable lengths.

3-05. Multiuse sportshall above the BIPV facade.

3-06. Black mounting brackets and modules give the façade a uniform appearance.

3-07. Mounting of the BIPV façade modules.

3-08. Details of BIPV module with mounting frame.



3-09. Detail of the all-black BIPV surface.

Interview with entrepreneur: Mr Haakon Tjomsland, CEO at NCC Construction Norway.

NCC aims be a leader in sustainable development. That is why it is particularly rewarding to build a school with such clearly defined environmental goals, where also new generations will get insights into energy and environment. The building site has followed the NCC ‘Green building site’ concept, which places stronger demands on energy usage and waste handling than what is required by the government.

Interview with vice mayor for Business Development and Public Ownership in Oslo City: Mr Geir Lippestad

Brynseng school is in many ways a model project for others and we are proud to showcase this school. It is extremely important that Norway builds this competence, both for the sake of the climate, and for the business and building industry. We want to be in front when it comes to environmentally friendly buildings.

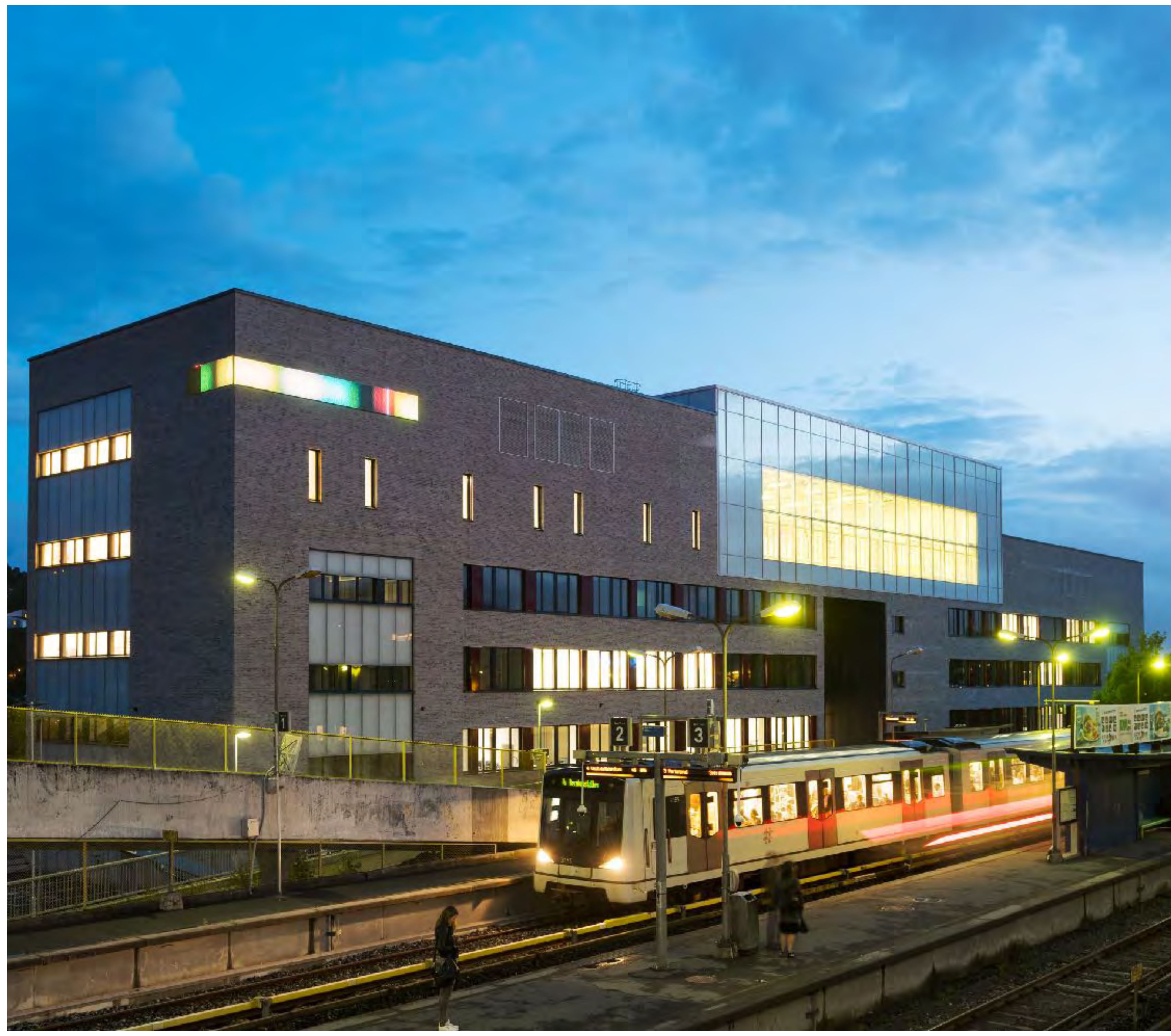
3-10. Vice mayor Geir Lippestad (right) in conversation with the project architect Ida Hexeberg (left). In the middle Undervisningsbygg CEO Rigmor Hansen and Department leader NCC building, Are Strøm.

3-11. *The completed BIPV façade of Brynseng primary school in Oslo.*

Finance
The PV system was planned within the economic framework of ordinary investment and financial support from Enova. The project would not have been built without Enova funding, which covered the added costs associated with achieving the nZEB goal. Income from the PV system was not a driver for the project. The higher costs were accepted as this was a pilot study. The total cost of the BIPV façade was 792 €/m^2. Compared to a normal brick façade, the additional cost of the BIPV system was 469 €/m^2. If no financial support is included, the net present value of the BIPV system is negative. With financial support and the 'savings' from the replaced brick façade included, the investment is paid back in 20-25 years. The cost distribution was: BIPV modules 29%, inverters and cabling 16%, installation including materials and work 40%, project management 10%, other 5%.

Lessons learned
BIPV is still new in Norway, which became apparent during the tendering process. There were few reference systems and none of the suppliers had experience with a total delivery of solar modules integrated into a façade. The BIPV system was added late in the pre-project phase, and as a consequence the architect was not able to make all desired adjustments. After the BIPV façade was included, the building was redesigned to place a sport hall on the top of the building. This causes some shading of the PV system.
Obstacles during the project included costs and unclear regulations. The clarification of specifications for the fastening system and fire safety regulations required a lot of own work from the building owner.

The local fire brigade did not have previous knowledge about PV systems, but were happy to receive information and perform an inspection. Important lessons learned include ensuring that the project and design company has sufficient competence, identifying regulations and requirements early in the process, knowing who should do the mounting and electrical works, and using clear evaluation criteria for the testing, instrumentation and commissioning of the system.
New BIPV projects are now being planned without financial support. This would not have been possible without the knowledge and competence obtained in this pilot project. The use of standard modules instead of customized sizes and a more efficient process will substantially reduce costs.
Offers from suppliers competing for new BIPV projects indicate that costs may be halved compared to the Brynseng pilot study. The lessons learned are transferred to new projects through the national programme «Futurebuilt» and the research project «Building-integrated photovoltaics for Norway».


3-12. Front entrance of Brynseng school.

Copenhagen International School (DK)

Project data			
Project type	New construction		
Building function	School		
Integration system	BIPV as façade cladding		
Location	Levantkaj 4-14, 2150 Nordhavn		
Architect	C. F. Møller Architects	Year	2017
BIPV system data		**Producer data**	
PV modules	Custom-made	Producer	SolarLab
Solar technology	Monocrystalline with Kromatix glas	Address	Gunnar Clausens Vej 9, 8260 Viby, Denmark
Nominal power	700 kWp	web	www.solarlab.dk
System size	12,000 modules, 6,000 m^2		
Module size	700 x 720 mm		
Orientation	All façades		
Tilt	4° in four directions	Author/editor	Karin Kappel

Copenhagen International School (DK)

4-01. The completed BIPV façade.


4-02. Architect Anders Smith.

Interview with the vice-chairman of Property Fund ECIS, architect Anders Smith

Challenges

From the very beginning, I wanted to equip the façade with PV, but the contractor did not think it was possible. When the project started, I gave up on the idea at first. But as we got further along in the process, I couldn't resist – it had to be possible to find a solution.
The architects were originally working with three architectural module systems that didn't fit with the PV modules. In the course of the design process this was reduced to one architectural module system, so I drew up a sketch of a PV panel that fit with the module system.
I got the foundation on board with the idea, and then I convinced the architects that it was a good idea – in part because the PV modules are nearly cost-neutral in comparison to the originally proposed façades in aluminium mesh.
In the beginning there was resistance to PV among those designing and building the school, but now everyone thinks that it was their idea. It's been fantastic to witness this process.

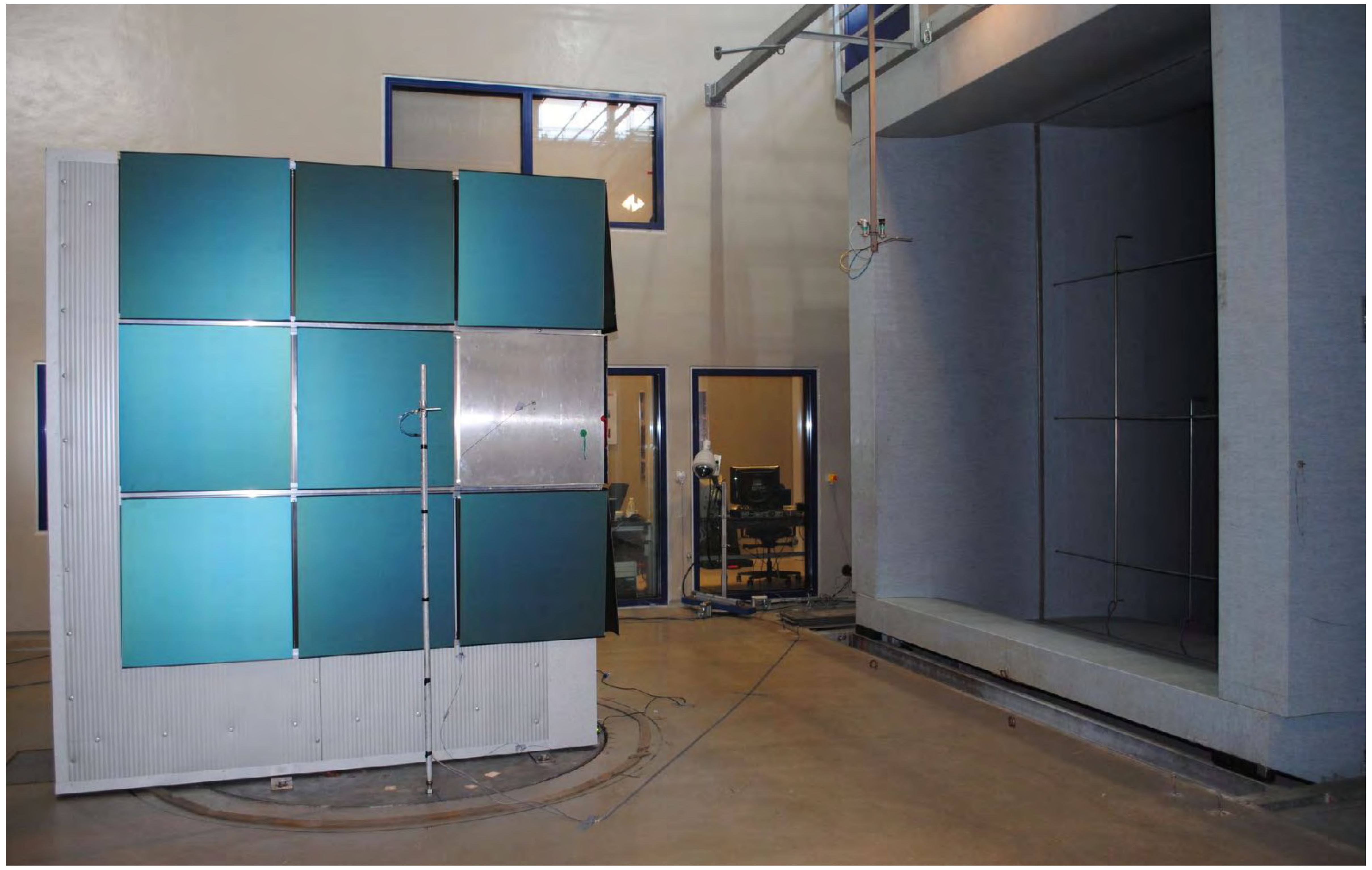
Aesthetics

I've always loved PV – both in terms of its materiality and its amazing function. But I hate the PV modules. They ruin a façade with their dimensions, frames and metal stringers.
We changed the visual look and scaled them down to the size of a façade panel. We don't want people to perceive it as a PV module. It's quite simply façade cladding.
I didn't want the school to appear as a black monolith, but instead divided into smaller blocks, creating a dynamic environment with room for diversity. The school should be colourful, with angled panels to avoid a blinding glare. I wanted it to look like a sequined dress. The architects suggested the colour green. So we chose modules with a green shade of chromatic glass.
Nanoparticles in the glass only allow one frequency of the light. Therefore, you only see the colour from certain angles – it simply reflects the light. This is amplified by the modules being tilted four degrees in four different directions.

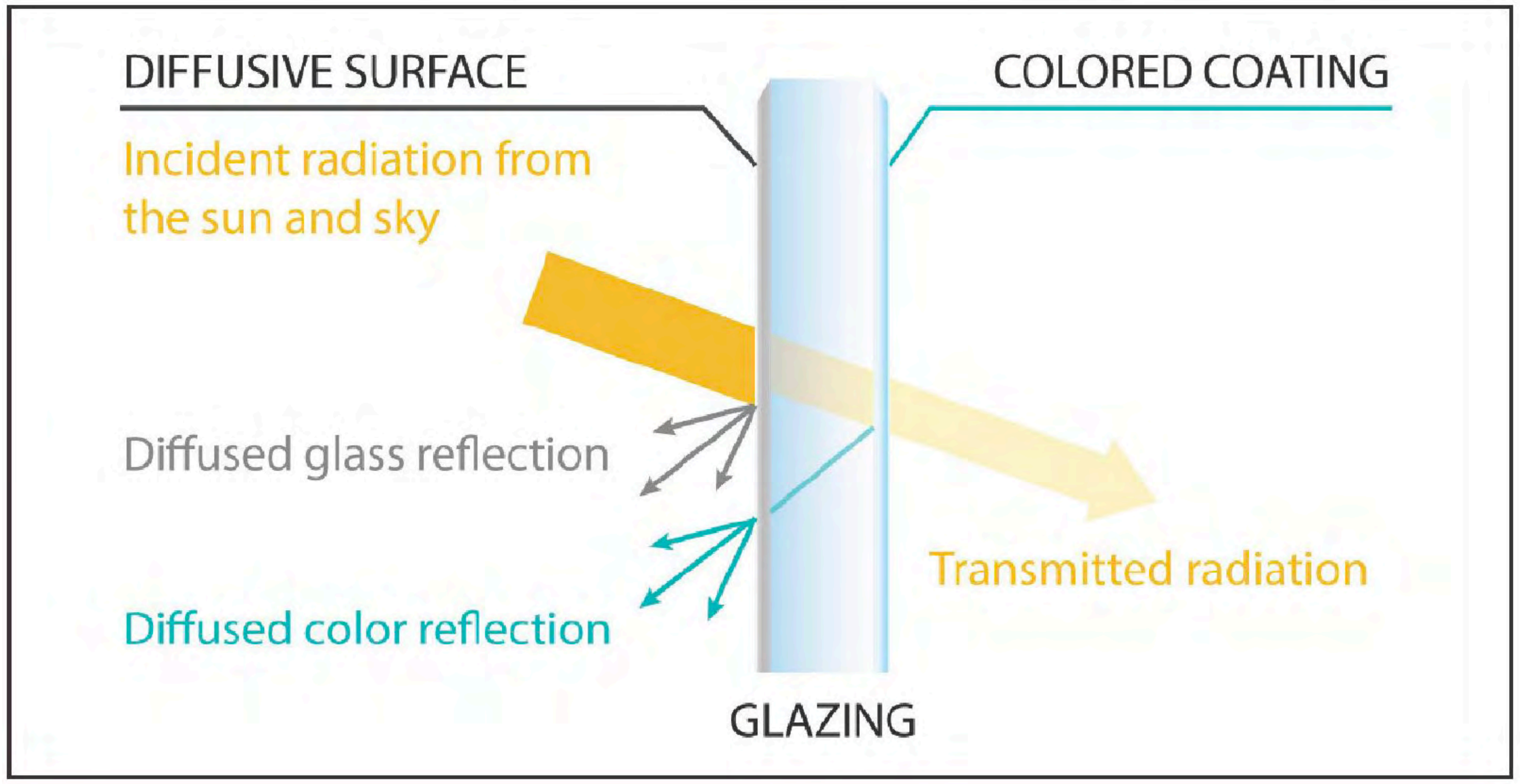
Decision-making
From the beginning, the client (ECIS) included the idea of a BIPV façade into the building project.
The goal was to be sustainable economically, socially and in terms of energy consumption. BAPV on the roofs was never an option as they are used as playground.

Process
The client, represented by the vice-chairman of ECIS, was personally involved in the project process and design of a new sustainable school.
The BIPV system was tendered in a total system delivery where the PV manufacturer acted as the main EPC contractor for negotiation and installation. Both plans and problems were solved in close cooperation between the EPC contractor, developer and developer's advisors (architects and engineers). As a result, the project was completed in time and within the budget, as part of building the new school.

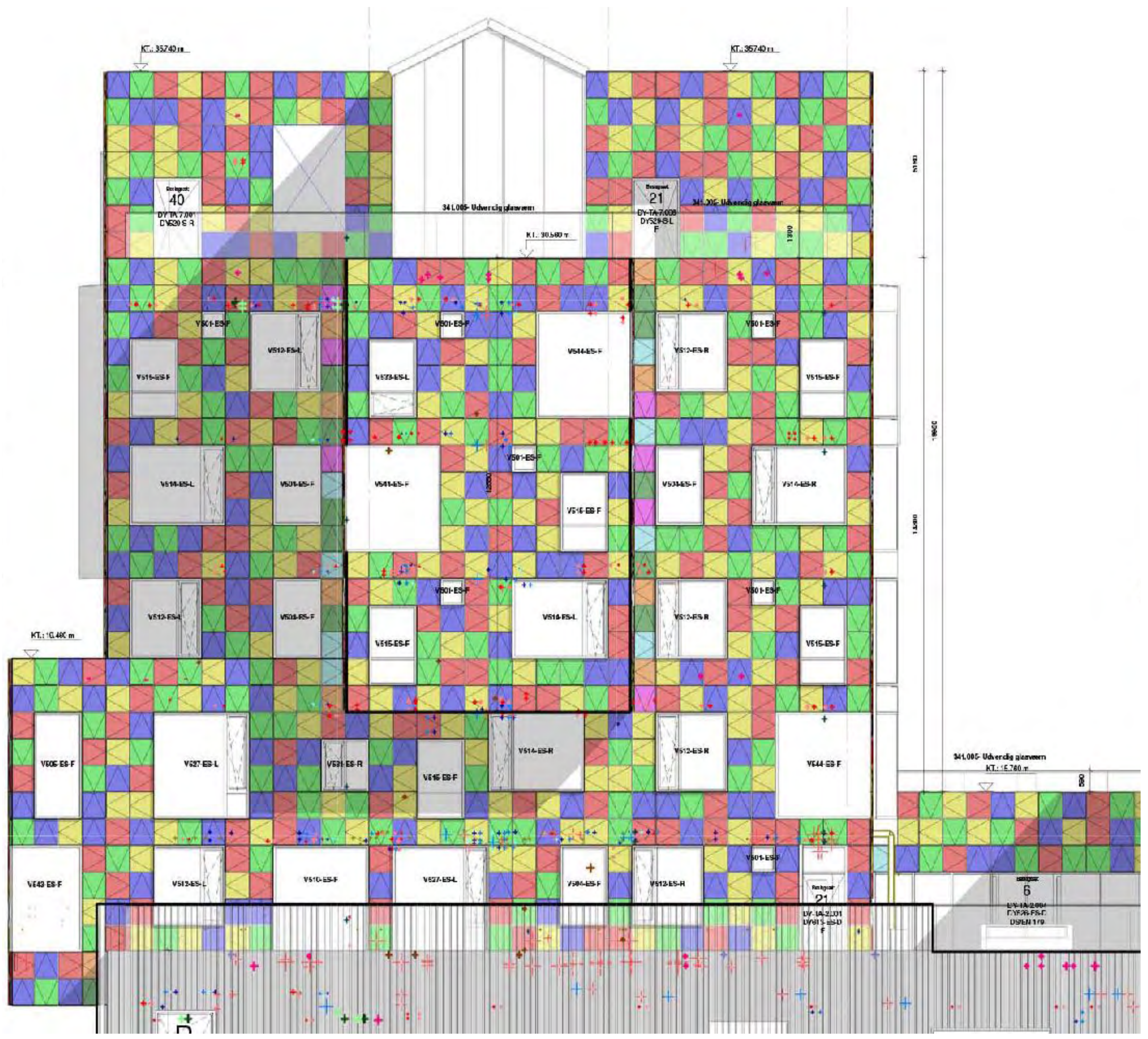
4-03. Detail of BIPV façade.



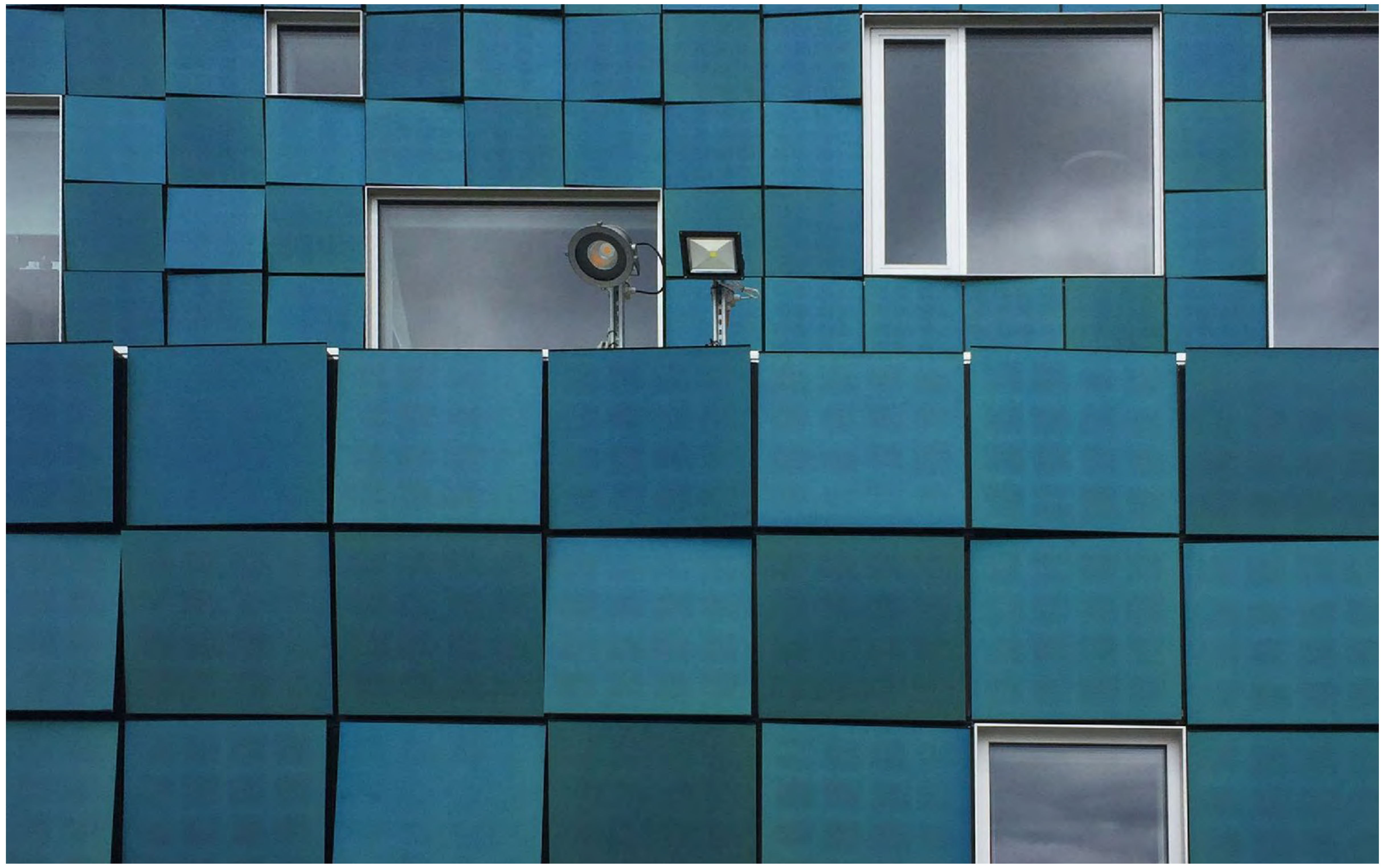
4-04. The façade system was tested in laboratories throughout Europe.



4-05. The colour changing façade: principle.



4-06. Drawing of how to place and angle the modules within the façade.



4-07. The angle of the modules within the façade creates different colours.

4-08. Close-up of the façade: the colours are depending on the angle of the module.

Building / system integration

Formal integration

Copenhagen International School (CIS) is located on the harbour in the new sustainable district Nordhavn.
The green, colour-changing façade is made of 6.000 m^2 individually angled PV modules. The concept was to make the façade look like a fishtail and this was possible to achieve with a special nano-structure technique on the panels, where one colour can appear in many different shades as the light changes through the day.

Energy integration

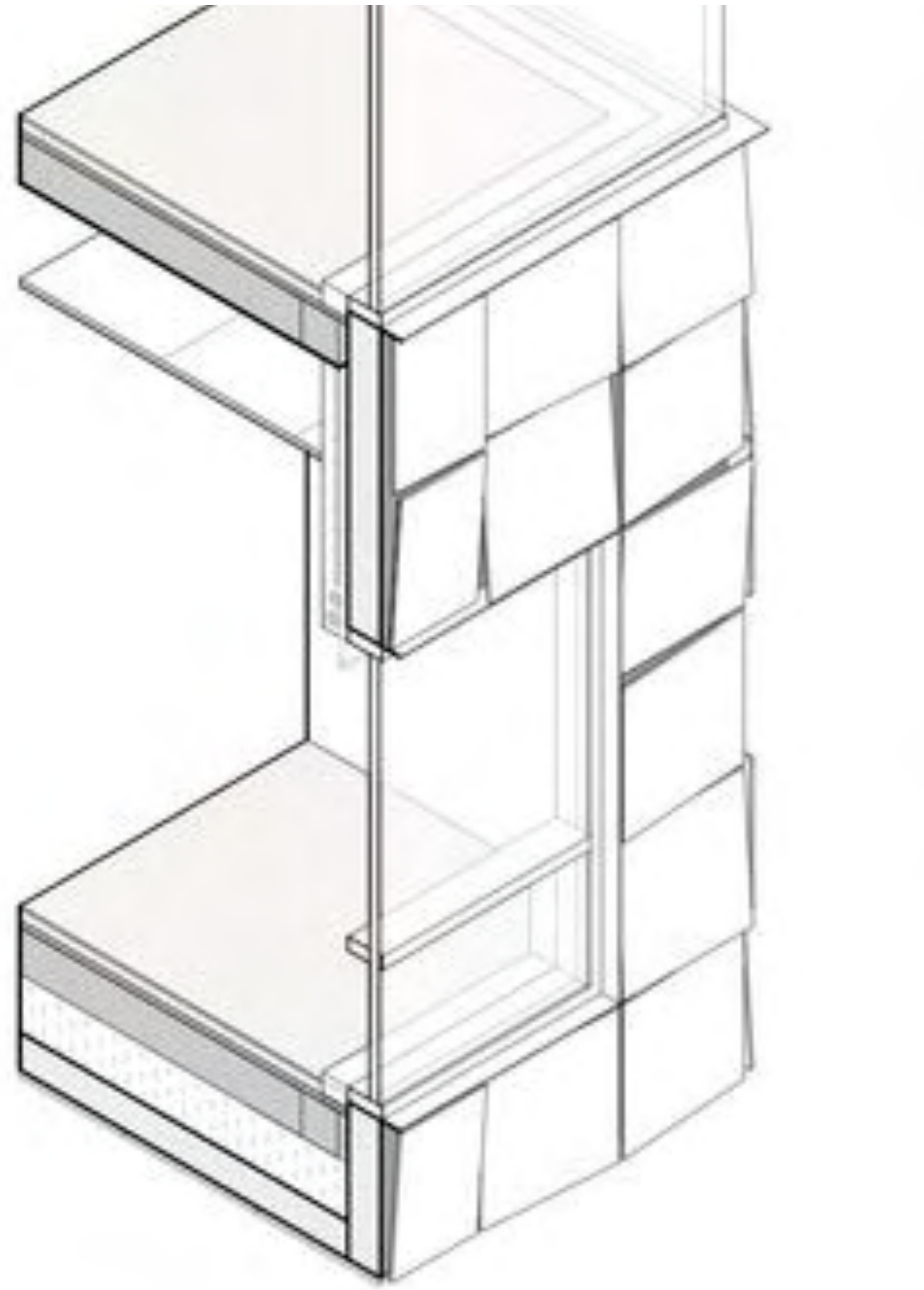
The school is built according to Energy Class 2020 [1] in the Danish Building Regulations (BR) and so airtight, that cooling is necessary even in winter. The expected energy consumption for cooling is one of the main reasons for choosing PV, and the energy production from the BIPV is estimated to cover 50% of the total annual electricity consumption at the school.

Technological integration

The 12.000 photovoltaic modules are mounted on the walls with a mounting structure specially designed for the CIS building. Each façade panel is made of a front panel (PV) and a cassette (aluminium) and the cassette gives the panel a slope of four degrees.
As the modules are individually tilted in four different directions, and the building has 70 different façades, shadows on the BIPV façade through the day are inevitable.
The effect of shadowing is minimised by the use of micro-inverters which optimize the energy yield for each 4 m^2 BIPV façade.
The micro-inverters are placed under the ceiling panels just inside the building, to allow easy serviceability by the school´s technical staff and thus minimize the operational cost.

[1] Energy Class 2020 is possible to achieve as a school when the total energy requirement for heating, ventilation, cooling, hot water and lighting per m^2 of heated floor space does not exceed 25 kWh/m^2 per year.

All façades are covered with PV-modules as the intention is to achieve overall holistic impression. The PV-modules on the north façade are not connected and also functions as reserves in case a module fails electrically on one of the active façades.
As the PV-modules are customized it makes replacement easy as the same size and colour is always available.



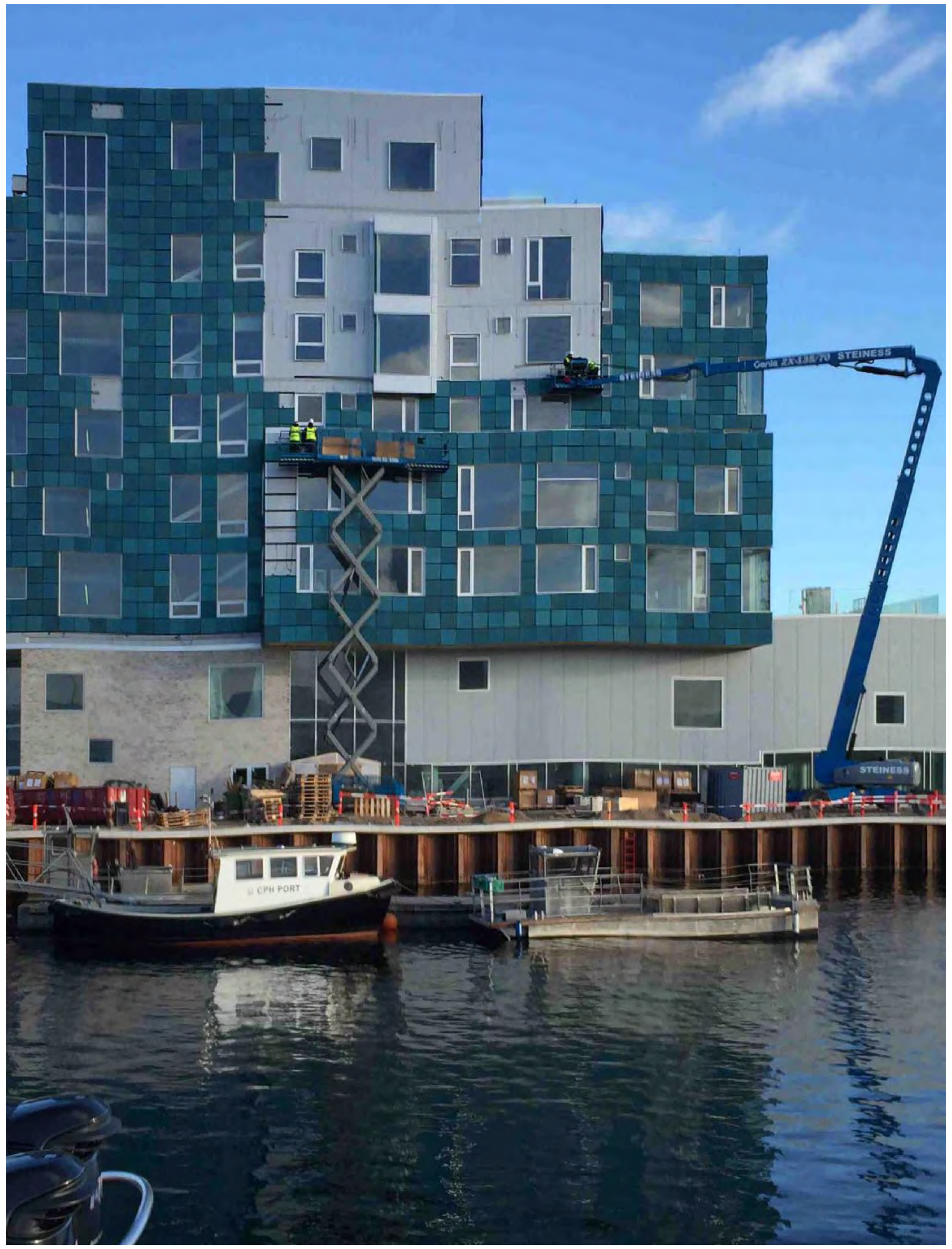
4-09. Detail of the façade with solar modules.

Installer Peter Melchior Rødder

It has been challenging to develop and build a complex BIPV façade like this. The PV modules had to fit into the architectural module system and the shadowing effects minimized with micro- inverters. For the mounting it was complicated to move around with a lift to install 70 different façades with protrusions in all directions. It took a long time to build. Access to the façades with effective machines is a major factor for time needed for installation.

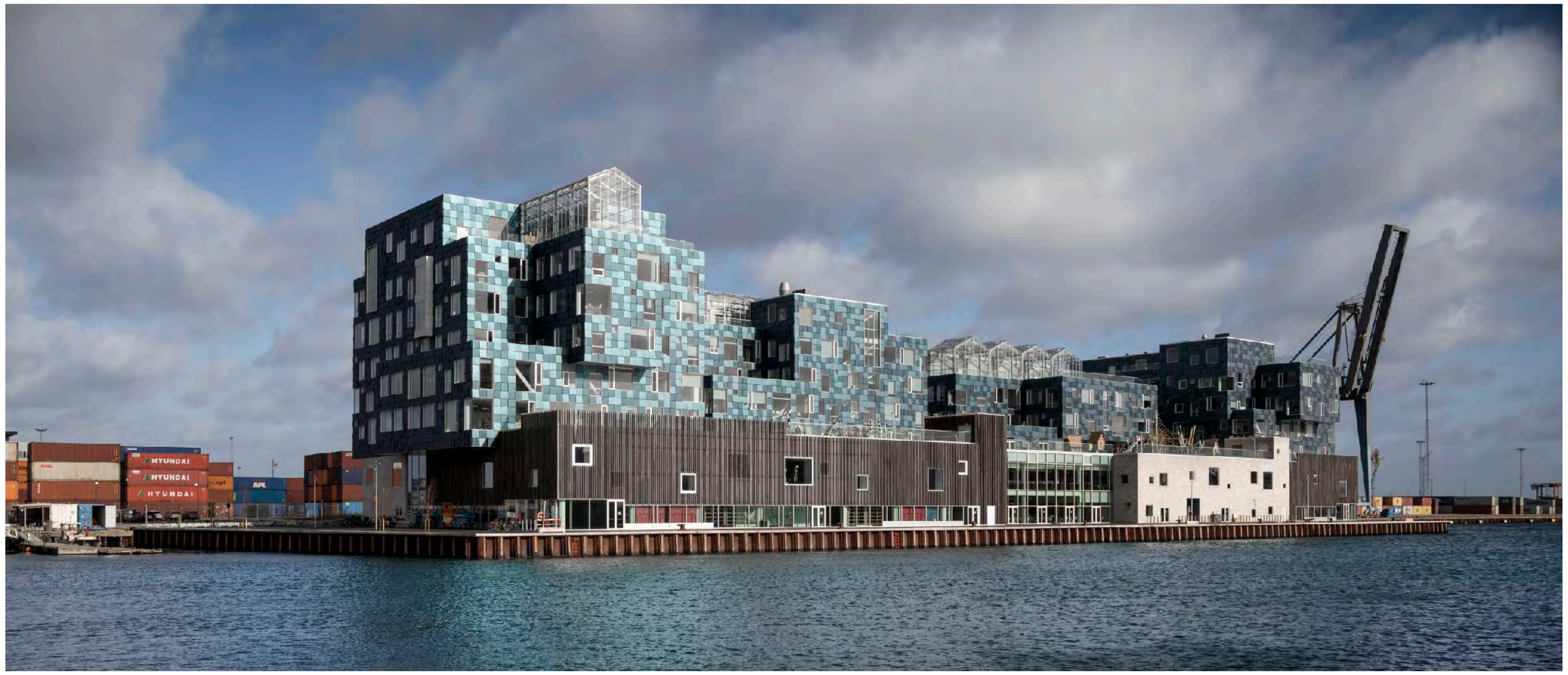
The solar modules are customized, not standard. Together with the client we completed a large number of tests: climate chambers, wind tunnel, and structural strength of the mounting system and the electrical system with micro inverters.

The PV plant worked for a short period, then it was stopped by the electricity grid utility for several months as the grid system was not prepared for input of electricity from large plants.
Today, the plant is functioning again as planned.



4-10. Access to the façade is a major factor for affecting installation time.

4-11. Prototype of the façade with Kingspan elements, solar modules, mounting system with brackets and rails, silicon joints, was built for tests.



4-12/13. The colour changing façade.

4-14. *BIPV north façade.*

Finance

The school established a property fund (ECIS) with the purpose of building a new school including the BIPV-system. ECIS was supported by five funds, of which one donated 27 million Euro to the construction of the school.
The school is tenant at ECIS and must be run in the most economical way in the next many years. To achieve this is installed BIPV. The intention is to get the highest possible self-sufficiency in order to lower the operation costs as tenant.

Lessons learned

It is important to keep BIPV in the discussion through the whole process as stakeholders can have bias against it. BIPV was about to disappear from the project a couple of times, but ECIS had an insisting vice chairman who kept BIPV in the discussion and at the same time was the driving person behind the design of the façade.

Umwelt Arena Schweiz, Spreitenbach (CH)

Project data			
Project type	New construction		
Building function	Exhibition and conference centre		
Integration system	BIPV ventilated roof		
Location	Türliackerstrasse, CH - 8957 Spreitenbach		
Architect	René Schmid Architekten AG	Year	2012
BIPV system data		**Producer data**	
PV modules	3S MegaSlate® II 160 W_p	Producer	BE-Netz / Meyer Burger
Solar technology	Monocrystalline	Address	Schorenstrasse 39, 3645 Gwatt (Thun)
Nominal power	737 kW_p	web	www.meyerburger.com / www.benetz.ch
System size	5334 m^2		
Module size	3'663 standard modules and 1'644 special		
Orientation	North, East, South, West		
Tilt	Variable	Author/editor	Pierluigi Bonomo

Umwelt Arena Schweiz, Spreitenbach (CH)

5-01. Umwelt Arena. One of the main façades.


5-02. Architect René Schmid.

Interview with Mr. René Schmid Architekt FH/SIA (René Schmid Architekten AG).

Why and when did you (as an architect) decide to approach for BIPV?
I had the chance to provide design input when my father built his first photovoltaic façade 30 years ago.

To what extent did this experience influence your following projects? Could you tell us the lessons learned and the obstacles?
It showed that electricity generation could be successfully integrated with a building façade, but the obstacles were the fixed shape and the shiny dark blue appearance of the PV modules. We have tried and learned different techniques to overcome those obstacles, by creating matt finishes to reduce reflection or colours away from the standard blue, black or brown. Today it is much easier, as PV modules come in many different colours, materials and compositions, with more innovations on the way.

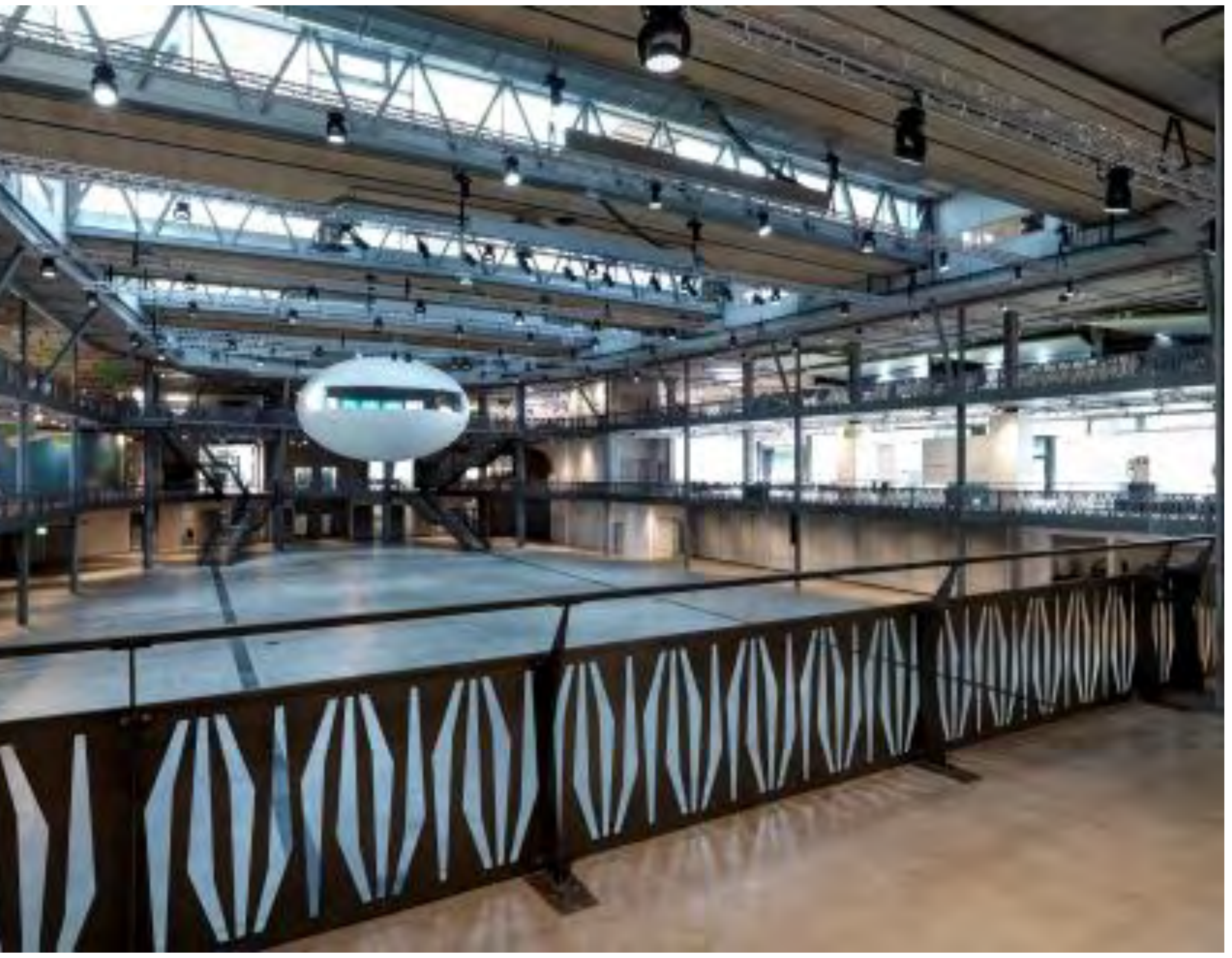
How does the PV technology affect / stimulate contemporary architectural semantics / aesthetics?
In the past, PV has influenced architecture in a negative way with its visually unappealing standard modules that often appear as alien elements on roofs and walls. Now, with the new array of options for colours and patterns as well as the aesthetic and structural integration of PV into the building, possibilities for artistic expression are endless. Some of the most spectacular buildings in the world incorporate solar energy in creative ways. Hopefully this will inspire more and more architects, investors and homeowners to embrace solar as a standard building tool.

Decision-making
Walter Schmid is a building contractor and energy pioneer with a broad experience in projects in the areas of energy efficiency and the use of renewable energy. He planned the Umwelt Arena Schweiz in Spreitenbach (near Zurich) as an environmental arena and interactive exhibition on sustainability. With its award-winning construction, the building itself is part of the exhibitions which can be visited with tour guides. The arena offers more than 40 different exhibitions for individuals, families and professionals over an area covering 11,000 m^2.

Process
In 2011 Switzerland's largest building-integrated photovoltaic installation incorporated the integrated MegaSlate® roof system from 3S Photovoltaics (a member of Meyer Burger Technology Ltd.). BE Netz was responsible for the installation.

CO_2-neutral construction site
The protection of resources plays an important role not only in the operation of the Umwelt Arena, but naturally the impact of the construction itself on the environment should be as low as possible. The world's first CO_2-neutral large-scale construction site used recycled steel for the construction, for example, and the 80,000 m^3 of excavated soil were used as aggregate for the cement production. The electric power for the construction site was partly generated by solar cells on the site containers as well as a windmill on the crane, while the construction vehicles ran on biogas or biodiesel.


5-03.BIPV roof detail.



5-04. View at the interior space for exhibitions.

5-05. A detail of an exhibition space.

Building/system integration

Formal Integration

The Umwelt Arena is the first Swiss centre of excellence for the environment with the widest integrated PV plant. The roof, with a modern architectonic design arranged like the scales of a reptile, has an octagonal PV system with 33 different surfaces, differently oriented, with slopes ranging from 6° to 62°. It stretches almost down to the ground, in the manner of a dome and is completely covered with PV modules.

Aesthetic Integration

René Schmid was looking for a shape that expresses dynamism and athleticism. It is inspired partly by the outstretched wings of a bird and partly by the world of fast cars and speedboats. The photovoltaic panels form the protective shell of the building like a reptile’s scales. Its facets and the darkly gleaming panels are reminiscent of a crystal. The heart of the building is formed by the three-floor Arena, which accommodates up to 4000 people. The architecture of the Umwelt Arena is an example of how ecology and economy can be harmoniously combined in the shape of a modern building.

Energy Integration

The PV system was calculated to generate around 540,000 kWh per year, twice the amount of energy that it consumes, with a zero CO_2 balance. The electricity generated in one year is equal to the consumption of 120 private houses or 300 electric vehicles. Other energy production systems are thermal solar panels and a biogas process based on food waste.

Technological Integration

The envelope is realized with prefabricated wooden sandwich elements and good thermal insulation.
The solar modules are frameless and produce energy on 33 different triangular and trapezoidal surfaces. The solar plant is composed of 3663 standard modules and 1644 with special shapes.

Finance

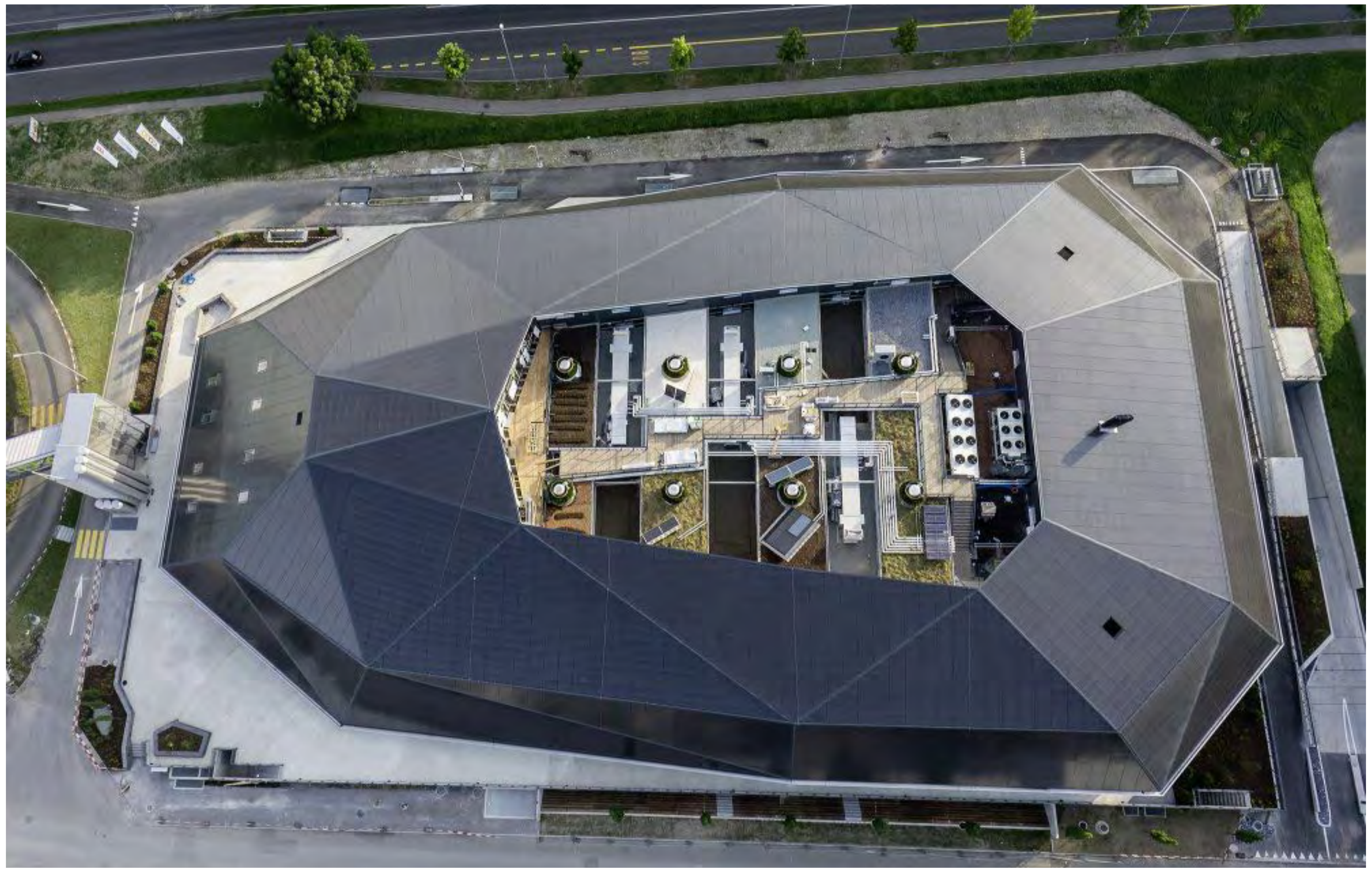
The operating costs of the arena are reduced thanks to the renewable energy. Furthermore, a solar thermal system is used to cool the building in summer and heat it in winter with an innovative system. The equipment used for this system and the appliances used in the Umwelt Arena run with the self-generated electricity. Some of the surplus electricity is stored and/or used by neighbourhood properties.
Funds for the realization of the Umwelt Arena were received from leading Swiss partners recognising its strategies with regard to the sustainable energy supply and the importance of the natural habitat.

Lessons learned

The complexity of architectural shapes is not a limit. An octagonal plant with 33 different surfaces, differently oriented, and with a slopes ranging from 6° to 62°, which stretches almost down to the ground, in the manner of a dome, is just the beginning of an adventure to make this building active, sustainable and showcasing interactive solar architecture.

5-06. BIPV roof overview.

5-07. The BIPV roof system (5,300 m²), generates around 540,000 kWh of electricity per year.



5-08. The complex shape is completely active thanks also to special custom-made modules.

5-09. Detail of the roof mounting system with overlapping tiles and watertight construction.

5-10. Umwelt Arena during construction (the building site itself was CO_2 neutral).

5-11. *In spring 2012, Umwelt Arena's roof, which has an area of 5,300 m², generated approx. 540,000 kWh of solar power per year, roughly corresponding to the annual consumption of 120 households. This power is generated by 5239 solar modules produced by 3S Swiss Solar Systems and installed on a total of 33 differently oriented trapezoidal facets of the roof.*

Commercial Buildings

"Aktiv Energy Tower" Fronius, Wels (AT)

Project data			
Project type	New construction		
Building function	Office building		
Integration system	BIPV façade		
Location	Froniusplatz 1, Wels 4600		
Architect	Architekt DI Heinz Plöderl/PAUATArchitekten	Year	2012-13
BIPV system data		**Producer data**	
PV modules	Custom-made BIPV façade	Producer	ertex solartechnik GmbH
Solar technology	Monocrystalline silicon	Address	Peter Mitterhofer Straße 4, 3300 Amstetten
Nominal power	38.8 kW_p	web	www.ertex-solar.at
System size	146 glass façade modules		
Module size	Customized		
Orientation	South, east, west and dummy modules on north		
Tilt	90°	Author/editor	Dieter Moor

"Aktiv Energy Tower" Fronius, Wels (AT)

6-01. Fronius, BIPV west façade.

Interview with PAUAT Architekten ZTGmbH, architect Heinz Plöderl

Challenges

In 2007, Fronius initiated an architectural competition for an innovative renewal and redevelopment of the the existing company location and building structures of the former industrial district near the train station of Wels.

Heinz Plöderl´s concept was for a rear-ventilated curtain wall with PV-cells enclosed within vertical glazing to develop an impressive façade for a new identity and business launch for Fronius global sales hub.

Challenges related to the optimal integration of the BIPV system into the building, taking the expected energy gain of façade integrated solutions into consideration, determined the process from development to realization. In addition to the energy gain of the BIPV system itself, we especially paid attention to the influence of the chosen PV module and module design and configuration on the daylight and shading situation inside the office building environments. In this context, also the optimal combination with sun protection glazing behind the BIPV façade was investigated in detail, aiming also to protect the building from overheating.

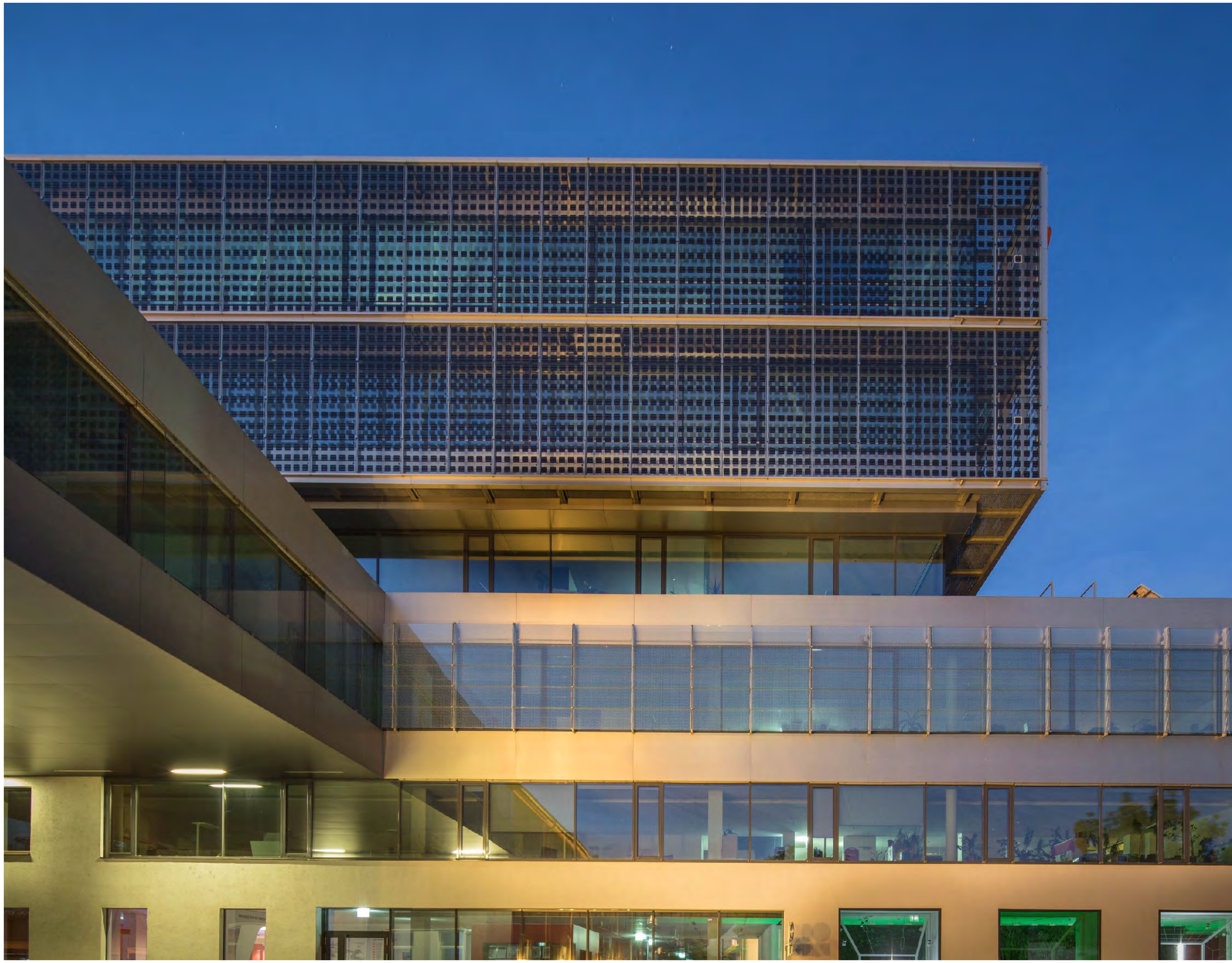
Aesthetics

Fronius International has a reputation as an innovative company being a specialist in welding technologies, as well as in the field of innovative solar energy and battery technologies. Therefore, it was very important for me to consider this innovative character of the company in the building's design. Thus, the design elements used were strongly identity-driven, which immediately brought us to the integration of innovative BIPV elements.

6-02. Architekt DI Heinz Plöderl/PAUATArchitekten

Decision-making
The decision to implement a BIPV façade into the building was raised by the architect and mainly driven by the intention to develop corporate identity for Fronius International at this location. The aim was to install a BIPV façade system that allows an optimal daylight situation inside the buildings environment, while still providing optimal energy gain.

Process
The renewal and renovation of the industrial area of the Fronius location in Wels was initiated in 2007 and lasted until 2013. The Fronius International "Aktiv Energy Tower" project, including its BIPV façade, started at the beginning of 2012 and was finished at the beginning of 2013.



6-03. Fronius, BIPV west façade.

Building / system integration

Formal integration

The "Aktiv Energy Tower" is located in a former industrial district of Wels with existing brick buildings constructed at the beginning of the 20th century. The project was the last step in redevelopment and renewal of this former industrial district surrounding the railway station in Wels to take on a new identity as the Fronius global sales hub.

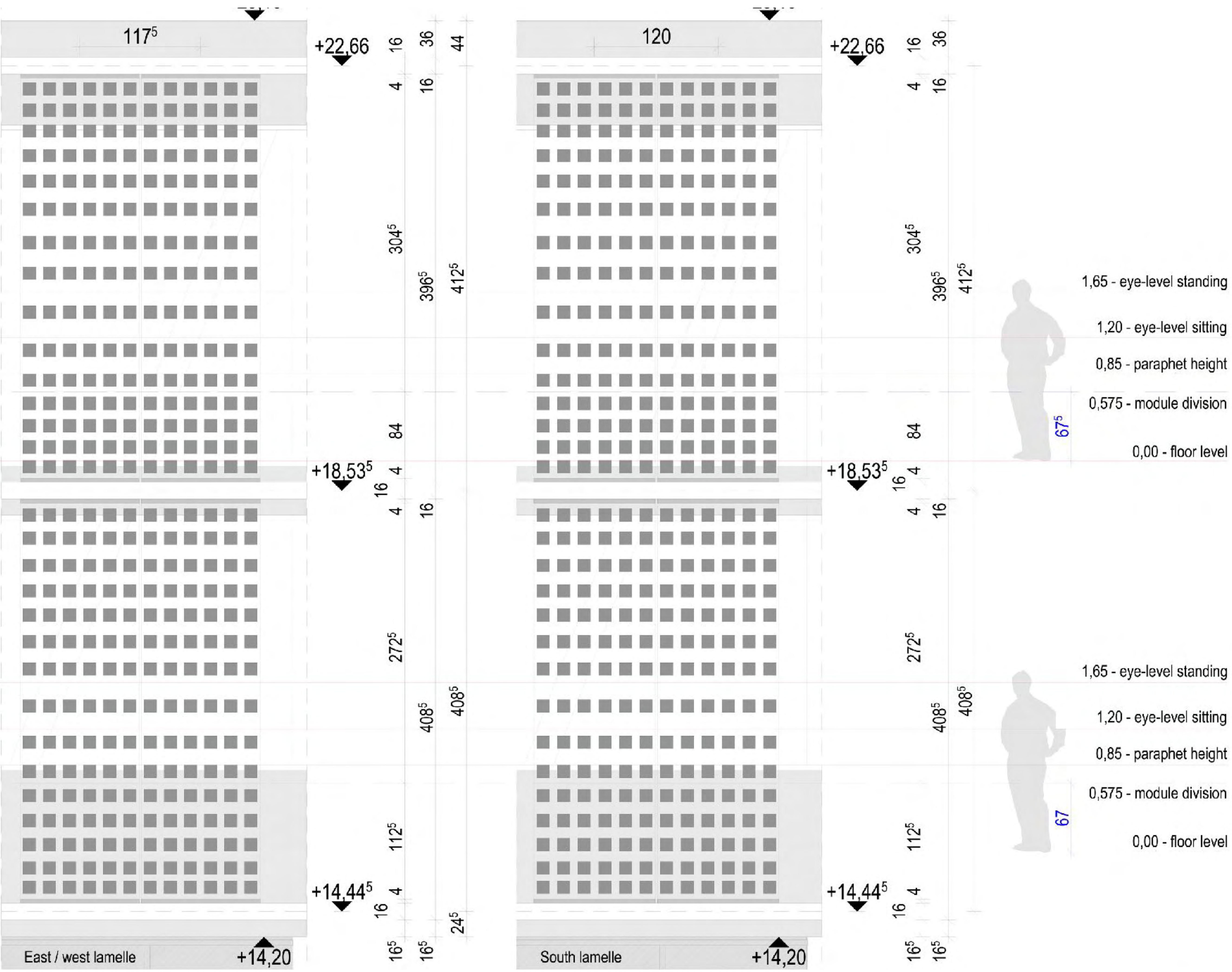
Energy integration

The office building is constructed to comply with the main aspects of the passive house standard, with energy for heating and cooling provided by geothermal heat pumps. In total, about 630 m² of BIPV façade elements were installed in the building. Next to the BIPV façade, also a roof-mounted PV system is used.

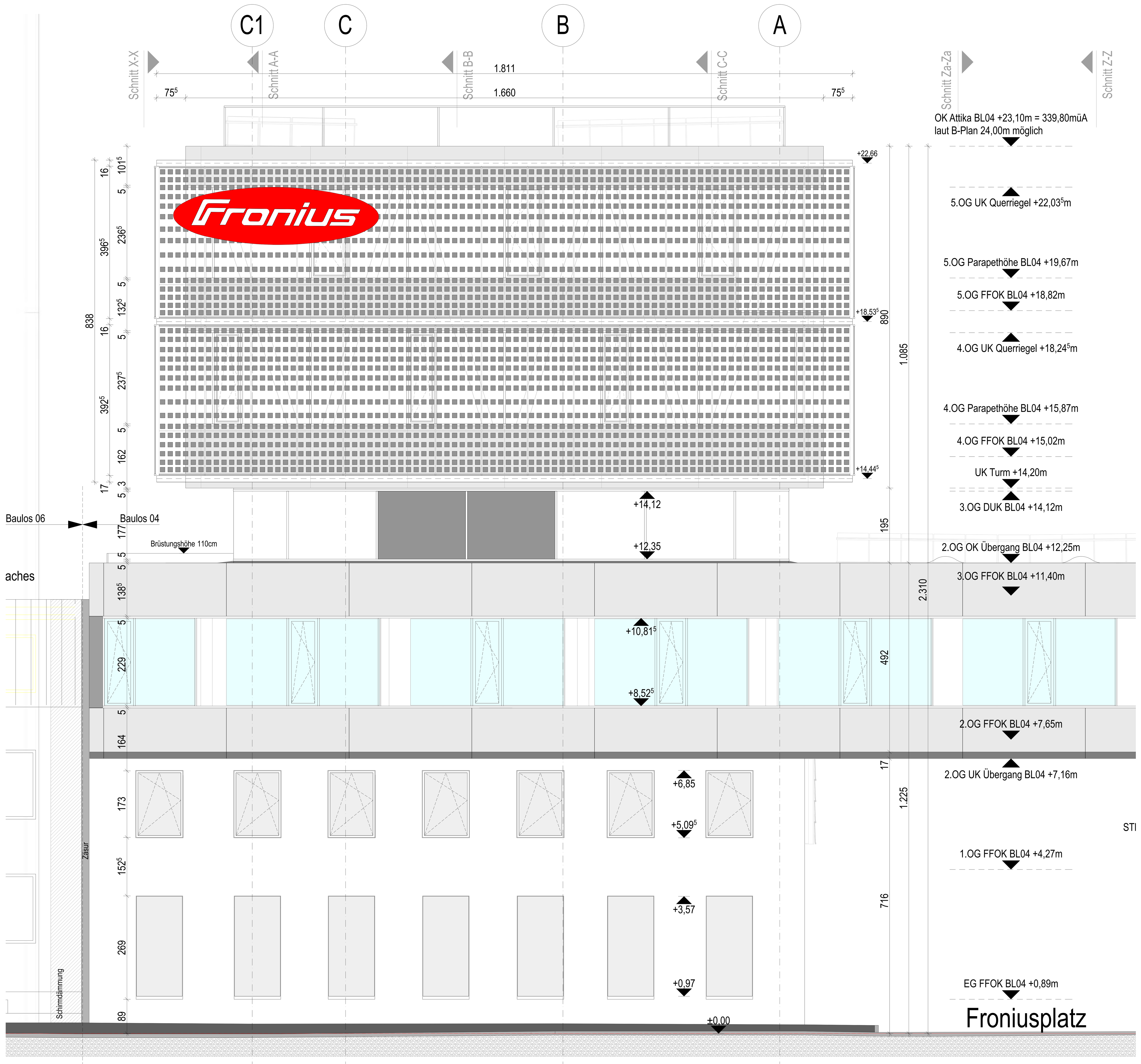
Technological integration

The laminated safety glass modules were produced using glass-glass technology and achieve maximum environmental resistance thanks to double-sided glass encapsulation. The monocrystalline silicon cells are incorporated to achieve a module transparency of about 63%, realized with increased distance between the cells inside the modules. In this way, ideal lighting conditions were realised in the office interior. In addition to the aspect of yield optimization, the BIPV façade was designed with the best possible interior lighting quality in mind. For this reason, the spacing between the modules is generous, which allows good visual contact to the surroundings. Furthermore, the BIPV façade is optimally ventilated and ideally accessible for maintenance and/or emergency exits through a catwalk structure behind the BIPV façade – therefore also meeting the safety requirements of construction regulations.

6-04. BIPV façade from the inside.



6-05. Fronius, drawing of BIPV façade, designed for viewing to the outside as well.



6-06. Fronius, drawing of BIPV south façade.

6-07. Dieter Moor, ertex solartechnik GmbH.

PV Supplier Dieter Moor, ertex solartechnik GmbH:

At the end of 2010 the architect proposed to integrate vertically movable sunshades with solar cells into the façade of the newly designed Fronius building. Several options and technologies have been investigated and compared with each other in the development phase. In this phase, the company ertex solartechnik GmbH provided many samples with different layouts to help the architect and the customer in the decision-making process. In addition to crystalline silicon cell technologies, also the thin-film technologies were considered because of their very homogeneous appearance. Also semi-transparent cells (with small holes in the wafer) were considered as an option. In the end, neither thin-film nor semitransparent technologies met the customer's expectations regarding the energy output and cost aspects. Also, the initially planned movable solution using sunshades was abandoned due to the high costs and requirements for the structure and also the glass - due to special requirements related the glass thickness, e.g. if the glass is fixed only on the short side of an element, the glass thickness would need to increase dramatically, which is related to the wind loads, among other aspects. Taking into consideration all of these variations and options, finally, all involved stakeholder, especially the architect and the customer/user were happy to have a "full-size" solution from ertex solartechnik GmbH allowing a quick and high-quality installation of the BIPV system.

Finance

The initiative to apply a BIPV system to the building's façade was taken by the architect and further realized by the financer and building owner/user, the company Fronius International GmbH. There were no specific financial incentives for the BIPV used. The BIPV system lifetime is foreseen to be longer than 25 years.

Lessons learned

The main driving forces for the realization of the BIPV façade in the Fronius office building were the architect himself, who was strongly supported by the customer Fronius – in person by Mr. Klaus Fronius himself. In general, the BIPV façade of this project brought about profound knowledge of the interaction between BIPV modules and configurations with solar-control glazing and its impact and influence on the daylight situation of interior office environments – thus, providing an important function of the overall building concept.

6-08. Fronius, night view of the BIPV façade.

ENERGYbase office, Vienna (AT)

Project data			
Project type	New construction		
Building function	ENERGYbase - Office Lab Edu Building		
Integration system	Exterior shielding on tilted façade		
Location	Giefinggasse 2, 1210 Vienna		
Architect	Ursula Schneider, pos architekten ZT gmbh	Year	2008
BIPV system data		**Producer data**	
PV modules	Custom-made BIPV modules	Producer	SOLARWATT GmbH
Solar technology	Glass-glass laminates	Address	Maria-Reiche-Straße 2a, Dresden (DE)
Nominal power	48,2 kWp	web	www.solarwatt.de
System size	364 PV-Modules, ca. 400 m^2		
Module size	1520 x 710 x 9 mm		
Orientation	South		
Tilt	31.5°	Author/editor	Astrid Schneider

ENERGYbase office, Vienna (AT)

7-01. ENERGYbase, BIPV façade.

7-02. Ursula Schneider, POS architects.

Interview with Ursula Schneider, POS architects.
"It was by chance, that the right people were together at the right time at the right place to carry out this project together"

Challenges
The aim was, to make PV visible on the façade. At the same time the PV modules should be optimally oriented and ventilated to achieve the highest possible solar yield. At the time, when the building was planned, in the early 2000's, PV modules were so expensive, that the yield optimization had high priority. At the same time the office building should be transparent and well day-lighted. Thus a large share of about 70% glazing was chosen for the south façade. It was obvious, that the south façade would need an exterior shading, optimally functioning in a passive mode, without motors, just by geometrical effects.

Aesthetics
In residential projects, the shading would be done by overhanging construction elements, such as balconies, whereas for office buildings, flat glass façades with cantilevered shading slats would be typical. This type of flat glass façade with little 'PV-roofs' seemed architecturally boring and from of low quality for the architect. So the idea of a folded façade arose: opaque PV-modules should provide shade while the tilted glass panes would deliver daylight.

Design & Comfort
It was a high-priority that on the one hand, the view to the outside would be good and undisturbed by the opaque PV-modules and on the other hand, the shading and daylighting of the interior should be optimal. The façade was therefore designed such that the lower row of windows would allow optimal views outside and that the upper row of windows would guarantee daylight deep into the office space.

Geometry
Two rows of PV and glass-elements were dedicated per storey to optimize the daylighting deep into the office space. The façade is a slightly offset with respect to the floors and ceilings, so that the light can fall deep into the room from a point higher than the ceiling.
The windows are tilted by 63.5° and are directed outwards to form a zig-zag-façade

together with the opaque façade elements. Those are made from wood with vacuum insulation panels inside. This way a slim appearance could be guaranteed.
“Architectural, design and functional integration including solar power generation optimization was more important than substitution of building materials”

The opaque façade elements were covered on the outside surface with sheet metal. The PV modules were installed on top of this layer with horizontal aluminium profiles on which they are held with glazing fixtures
To the architects, this seemed to be the optimal solution for the architects to allow a free ventilation behind the PV modules to allow maximum solar energy generation. To combine them to become a ‘glass roof’ would not have changed much, as the sheet metal would have been necessary anyhow to prevent rain from entering through the upper ventilation zone.
Furthermore, the PV modules are project a little to allow rain to drop down from the edges. The overall façade was tilted by 3° so that the rain would not flow onto the row below but drop down directly. However this means at the same time, that there is no self-cleaning effect due to rain. As the glass façade needs to be cleaned on a regular basis anyway, this does not cause a problem, as the dust effects do produce only small losses. While the angle of the tilted glass was chosen exactly according to the highest sun angle, some shading of the top row of solar cells in the modules occurrs at midday in midsummer. This leads to a drop in electricity generation. Probably the air gap between the façade and the resulting overhang of the PV modules were designed without taking this shading effect into account.

Decision making
Description by Tim Selke, who was working as scientific planning supporter on the project design.
“A Solar Façade should not only provide optimal solar power generation, but also thermal and visual comfort for the users”
The AIT, together with other researchers and the architects, carried out a study called ‘sunny building’, which showed the feasibility of realizing an outstanding solar design with highest energy efficiency and user comfort standards. In 2004 the owner gave the ‘green light’ for the realization.

7-03. Tim Selke, AIT.

The AIT was not only involved as the user, but had the opportunity to do detailed simulations and to advice on the building design: thermal building simulation, simulation of air flows, energy and user comfort and the design of the living lab PV-system with an inverter test facility.
Many simulations of variants were carried out to find the optimal solution for thermal and visual comfort and shading / daylighting solution as realized with the folded PV-façade.

In addition to the passive shading by the opaque parts of the façade, it became clear, that glare control would be needed for the summer case with the high-standing sun. Thus solar control-blinds were introduced to prevent glare in winter time or during morning and evening hours, when the sun comes from low in the sky. The blinds were carefully simulated, analysed and designed regarding thermal effects, colour and perforation to allow maximum visual and thermal comfort. In the lower section, the blinds are coloured anthracite grey to allow optimal views to the outside, while the upper sections are of metal to reflect radiation and reduce the heating of the blinds. On the top of the south façade in each floor, the used air is collected and exhausted. The heat recovery system allows heat gained at the south façade to be used for preheating air on the north side. On the other hand, the air inlet at the north and the air exhaust at the south allow cross-ventilation providing maximum comfort with very low air speeds. A complete building automation and control system with over 500 sensors was installed and is today operated by a facility manager from Siemens.

Building integration

Formal integration

In a technical sense, this PV-system would be 'BAPV' – building attached PV. However given the deep integration in the building's appearance, design, geometry and functionality, this can be considered to be a BIPV system.

Energy integration

With respect to the energy base of the building, the design of the tilted façade is an 'energy design' in a triple sense: on the one hand, the PV façade system is perfectly oriented to receive maximum solar radiation; on the other hand, the PV and the insulated wall behind it are shading the interior rooms. This way a triple energy effect is occurring: first the shading effect; second the optimization of daylighting; third the optimization of PV-yield, including the light reflection effect. The tilted glazing reflects more daylight towards the PV-modules and this gives a higher yield due to the integrated energy design.
The monitoring from 2009 till 2015 revealed that 23% – 34% of the electricity consumption for the building operation is produced by the PV system and 69% to 77% of the PV production is self-consumed. The specific yield of the system is up to 983 kWh / kWp. This is about as much as a roof top system would produce.

Technological integration

Glass-glass-PV-modules are installed as ventilated façade elements in six long stripes. Besides electricity generation, the PV system serves as a 'living lab' for testing of different solar cell types (monocrystalline, multicrystalline and multicrystalline silicon with back contacts) and inverters.

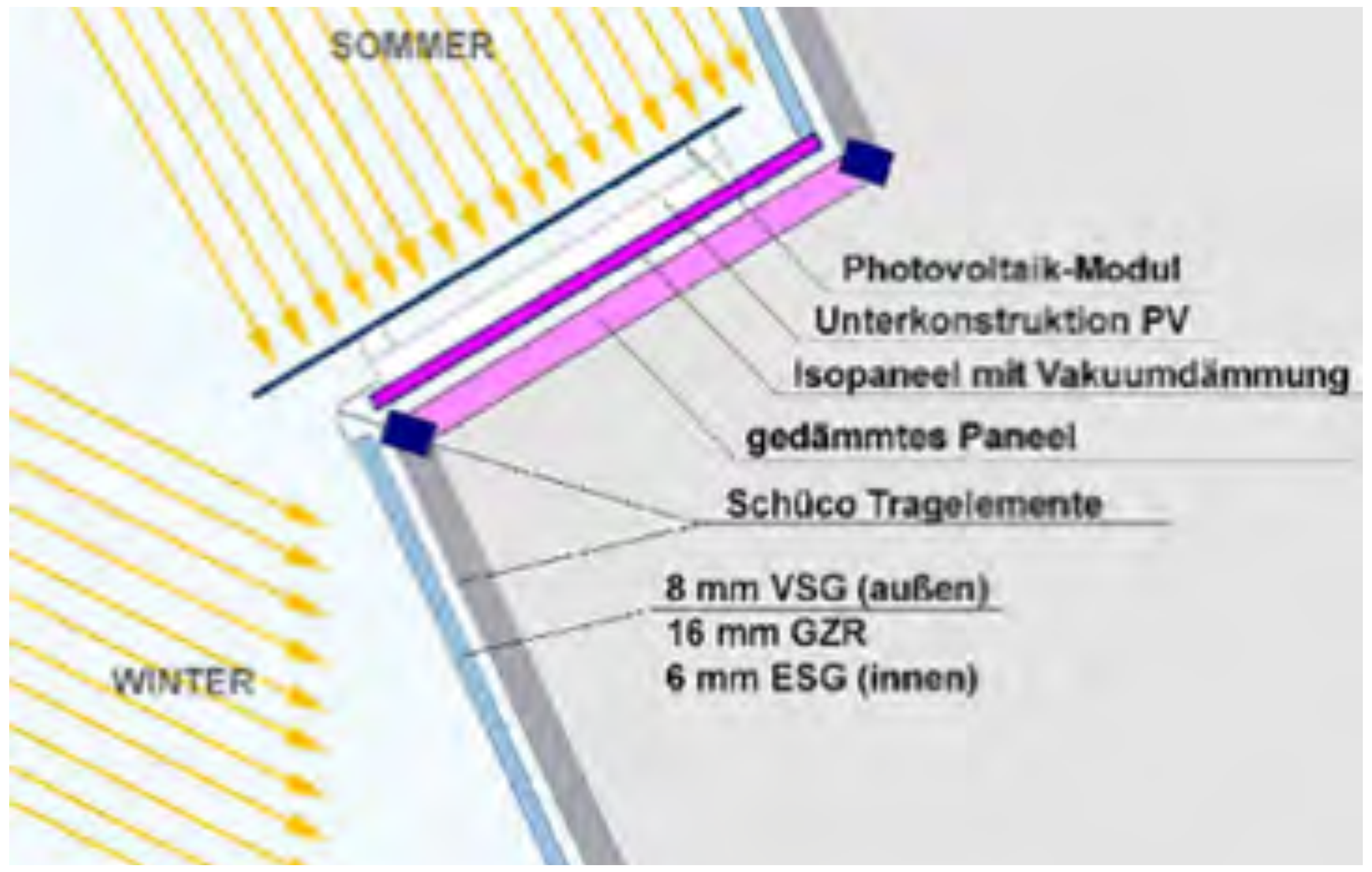
7-04. Zig-zag-BIPV façade with six stripes of PV and solar thermal collectors on the top.

Finance
The overall investment costs for the building are relatively low with 1,537 € per m^2 gross area incl. VAT. While it was possible to erect a nZEB building with passive house standard for these costs, occupants can now enjoy very low operating costs. The only 'external' energy-supply used and consumed is electricity.

Of the amount of electricity needed for the building operation between one third and a quarter is supplied by the PV system. The specific electricity consumption per m^2 useful floor area from the grid is only 14.4 - 18.1 kWh. This means that the specific energy costs for the building operation including ventilation, pumps, heating and cooling, are only 2.88 – 3.62 € per m^2 useful area and year. This is extremely low. The solar power is first used for this on-siteconsumption; only the surplus is fed into the public grid.

The installation was funded by the 'Ökostromfonds Wien' of the City of Vienna. The overall construction was funded by the European Union and the Austrian Ministry for Technology ('bmvit'). The research studies to enable the general concept generation and the scientific simulations of the energy system were funded within the framework of the 'Haus der Zukunft' (Building of the future) programme.

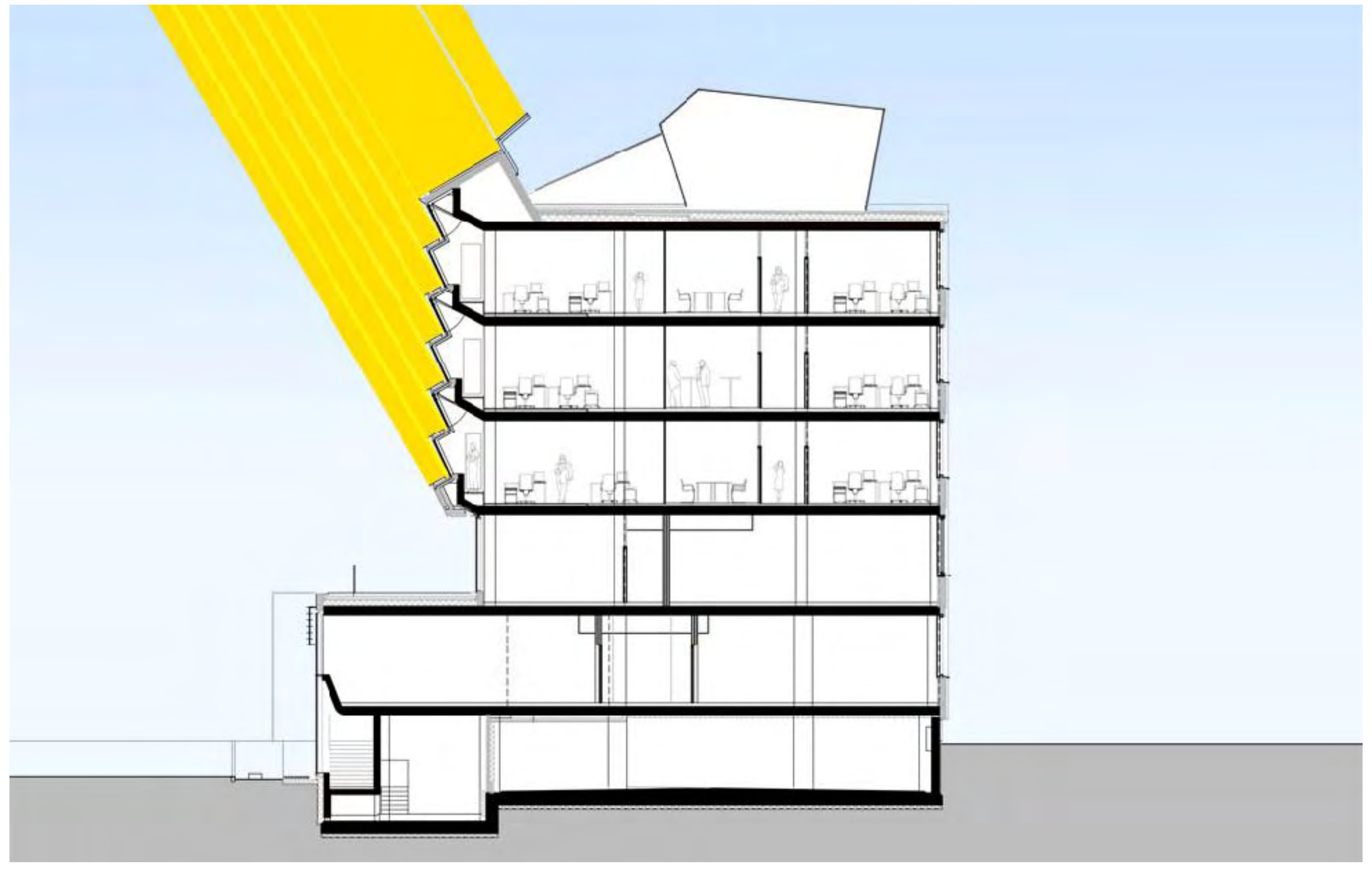
7-05 Open plan office.

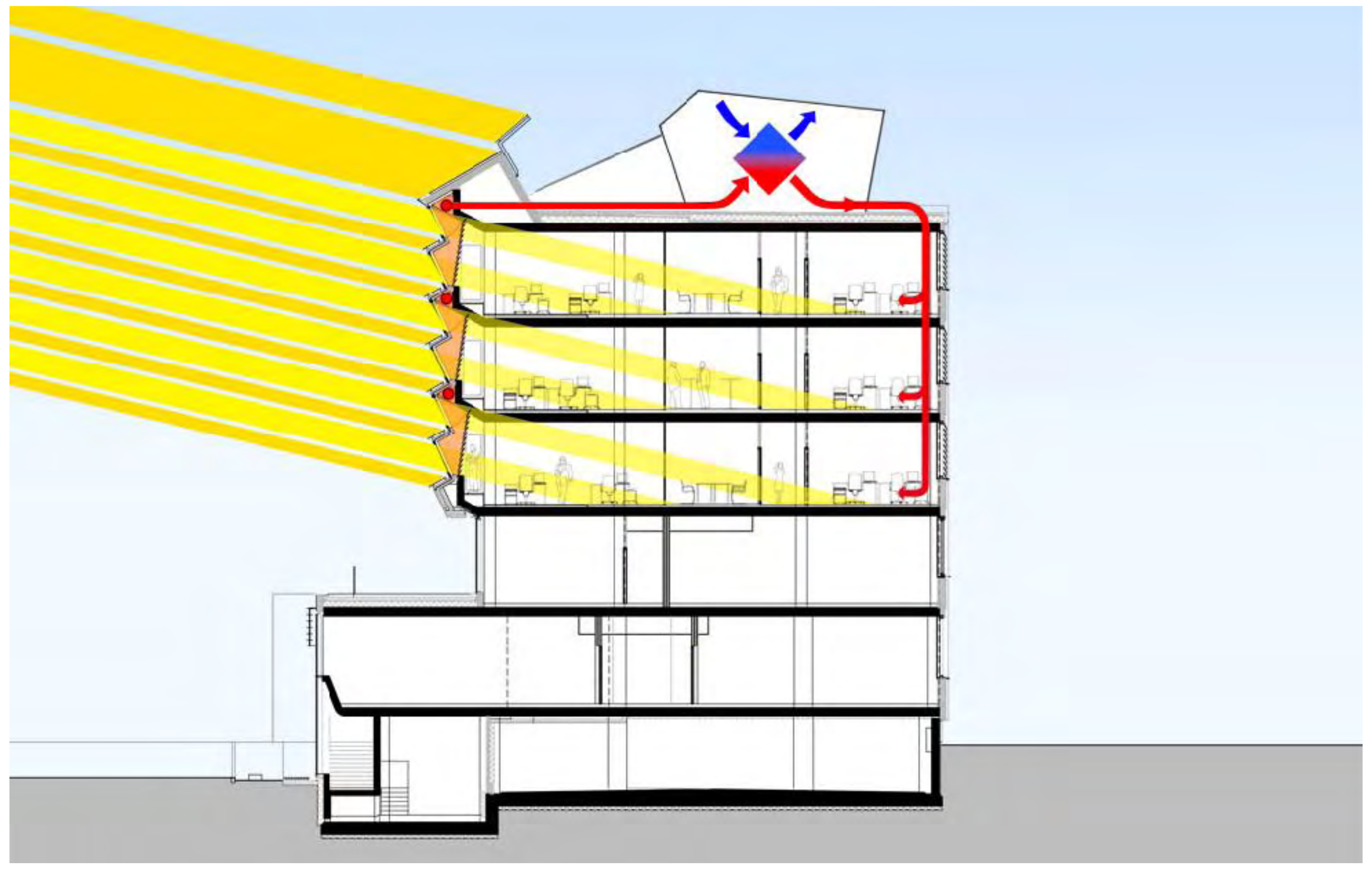


7-06 Façade section.

7-07 Folded BIPV façade.

7-08 Detail of the fixation.


7-09 Section with blocked summer sun.


7-10 Winter sun penetrating deep into the building.

Lessons learned

Economic view of the project
Building-integrated PV systems should not be evaluated only on the basis of their investment costs. The low operating costs of highly energy efficient buildings with a significant share of electricity generated by PV have a long-term value.

Integration of PV into the design
The integration of solar and other renewable energy sources and energy-conscious design go hand in hand. In this process, integration of PV into the building design and structure does not automatically mean lowering the efficiency of PV due to 'design concessions' such as colour printing or other colour effects minimizing the efficiency. The structural integration into the design plays a significant role as well as does the functional integration.

Controlling the detail sin PV façades
The detailing plays a significant role in the performance of PV façades. While the free ventilation and the reflections of the glazing play a very positive role the effect of small projecting parts causing shade cannot be overestimated. Even minimal overlaps can cause long shadows in the vertical, as can be seen with the solar module overhang in this project. The geometry must be carefully controlled in every detail in PV façades to avoid any shading.

Very valuable public funding for extended building design research
To be able to do such extensive simulations and differentiated planning process, public research funding is still necessary today. More research programs of this type should be carried out.

Today we could realize it 'Plus Energy'
At the time of construction, it was not possible to directly sell the solar electricity from the building and PV owner to the occupants. Today, other options have been recently introduced in Austria for 'community PV systems'. This means that today much more PV could be installed on the building to make it 'plus energy' or to supply also the user's electricity needs with solar power generated by the owner.

CIEMAT office building, Madrid (ES)

Project data			
Project type	Renovation		
Building function	Office building		
Integration system	BIPV façade cladding		
Location	Madrid		
Architect	Juan Carlos Gutierrez Garcia		
BIPV system data		**Producer data**	
PV modules	SunPower E18-305W and E20-327W	Producer	CIEMAT
Solar technology	Monocrystalline silicon (rear contacts)	Address	Avda. Complutense, 40. 28040 Madrid
Nominal power	Grid connected: 27.2 kWp, (P_{AC}=24 kW)	web	www.ciemat.es
System size	166.3 m² (connected), 172.9 m² (total)		
Module size	1046 x 1559 mm²		
Orientation	East, south and west		
Tilt	90°	Author/editor	Nuria Martín-Chivelet

CIEMAT office building, Madrid (ES)

8-01. CIEMAT office renovation with BIPV cladding.

Interview with the architect, Juan Carlos Gutiérrez, from the Architecture & Project Unit of CIEMAT. Additional comments by Nuria Martín Chivelet, from the Photovoltaic Unit, and user of the building.

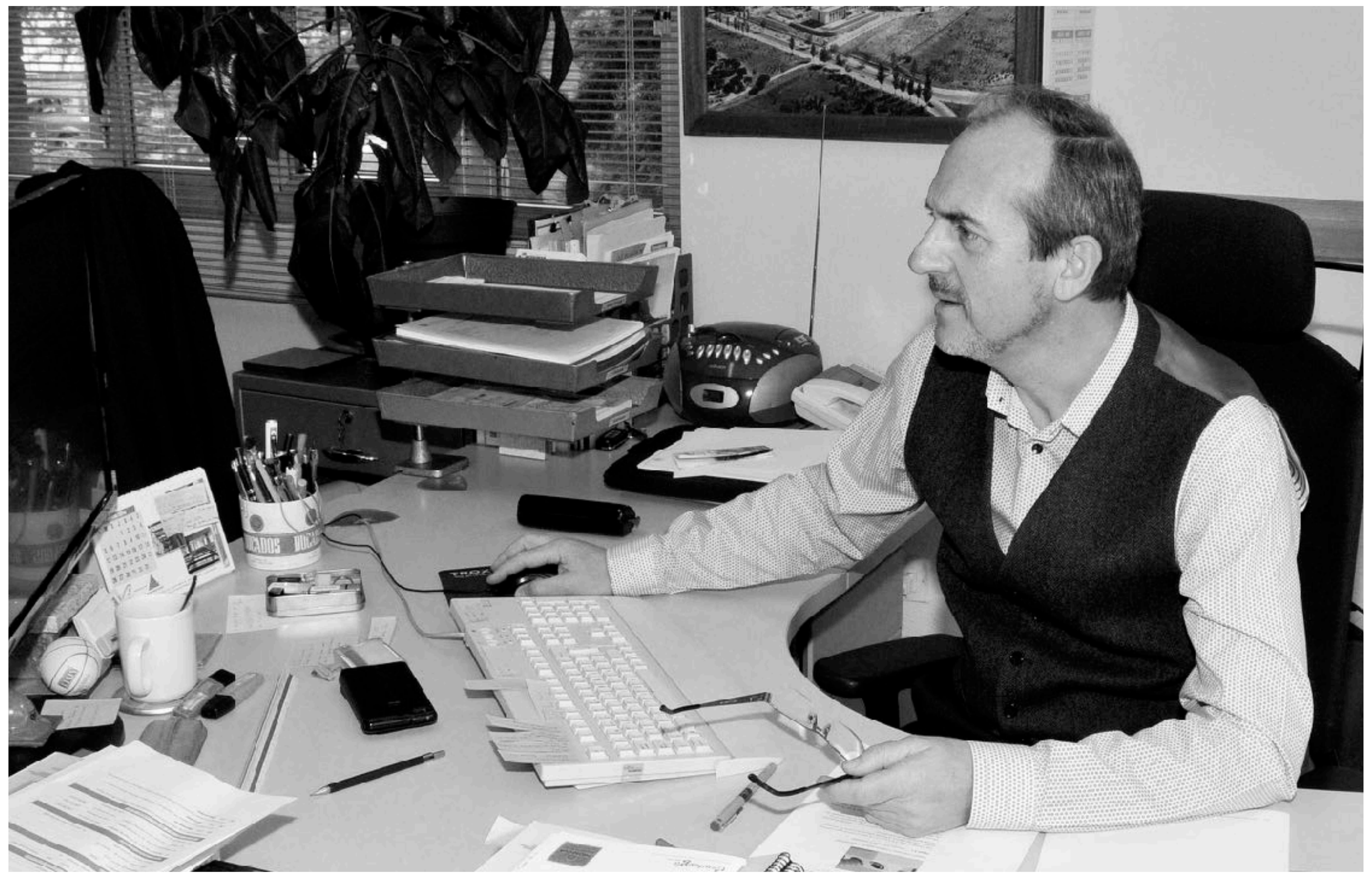
Both the Photovoltaic Unit and the Architecture & Project Unit of CIEMAT wanted to take advantage of the opportunity offered by this rehabilitation to include PV modules. Architect Gutiérrez had to accomplish the renovation of the building and also supported the idea of integrating photovoltaics. In this interview he explains the rehabilitation steps that lead to a BIPV ventilated façade.

Mr. Gutiérrez: This public building hosts the headquarters of the Renewable Energy Division of CIEMAT. It was built in two stages between the years 1970 and 1980, and has suffered some decades later from a series of quite serious structural problems. This led even to considering its demolition and reconstruction, but finally, it was decided to undertake integral complete rehabilitation in different phases to re-establish the building's structural safety conditions and meet the requirements the municipal authorities had been requesting. Once the stability problems had been solved with a new foundation in the northeast part of the building, retrofit of the roof was then undertaken, later the façades, and finally the interior spaces.
Several meetings were held among the implicated agents from the first stages of the project. Before the rehabilitation was defined, high efficiency mono-crystalline silicon PV modules, amounting to 15 kWp were available, which were considered to have suitable dimensions and appearance to achieve a good architectonic integration.

Mr. Gutiérrez: It was decided to implement a ventilated façade that, in addition to improving the building's structural condition and its energy efficiency, had photovoltaic modules integrated. The type of material for the ventilated façade was defined on the basis of the PV modules' characteristics, seeking a product that would allow for similar dimensions, such that someday, if necessary, the PV panels could be interchanged without detracting from the general appearance of the whole of the façade, and adapting the modulation and the general appearance to these elements such that the integration would be as effective as possible
The project succeeded in replacing conventional construction elements with commercial PV modules, which were integrated into the upper areas of the eastern, southern and western façades and distributed and connected to avoid major performance problems caused by partial shading. A varied set of working conditions and electrical configurations was searched for demonstration and learning purposes.

Mr. Gutiérrez: The combination of these elements with the polymer concrete panels used on the façades achieves good integration from an aesthetic point of view thanks to the similarity of colours and shapes. However, the integration has not sought to conceal the photovoltaic modules; rather it was considered that making them visible has a positive effect and provides a modern, exemplary image.

Decision-making
Decision-making was led by the architect of the centre, Juan Carlos Gutiérrez, who was in charge of the rehabilitation project, and supported by the General Director of CIEMAT, the Director of the Renewable Energy Division and the Photovoltaic Unit. The building had to be retrofitted after the technical municipal inspection, and the ventilated façade for the outer envelope of the building appeared to be the most suitable option. The renovation with BIPV would convey a positive message to the visitor, showing the use of renewable energy and serving as an easy-to-implement example for similar retrofit actions.



8-02. Juan Carlos Gutiérrez, architect.

Process
The architect met the PV researchers involved and the PV installer company Ehiso several times before the final project. The installer was responsible for the administrative formalities to legalize and register the photovoltaic system, a process that concluded in July 2015. The body in charge of the electrical installations in the Autonomous Community of Madrid authorised the installation after the certification of the low-voltage electrical installation classified as wet local with PV installation of more than 25 kWp (grounding resistance of less than 12 Ω and insulation over 0.5 MΩ).

8-03. CIEMAT office renovation with BIPV cladding.

Building / system integration

Formal integration

The building is located at the Ciudad Universitaria Campus in Madrid, and it is visible from the access road and the main avenue.
The photovoltaic generator is integrated into the ventilated façade of the three-storey building. It is made of large, standard, high-efficiency PV modules, made of glass/EVA/PV cells/EVA/white PVF.

Energy integration

The new ventilated façade has improved the energy efficiency of the building. The rated energy of the PV grid-connected system is 20 MWh/year. The PV modules are distributed over the southern, eastern and western façades, to achieve a flatter generation curve throughout the day, contributing to meet the building's baseline load over the year. All the electricity generated by the grid-connected PV system is instantaneously self-consumed in the building, which means a self-consumption index of 100 %.

Technological integration

The PV modules (SunPower E18-305W and E20-327W) form part of two photovoltaic installations: one of 27.2 kWp connected to the building's local electric power grid, and another stand-alone system of 4.9 kWp. They occupy a total surface area of about 176 m^2, replacing conventional construction elements, and are integrated into the upper areas of the façades, in order to receive more solar irradiation. They are back-ventilated (not airtight gap of about 100 mm). The eastern façade PV system is divided into three sub-systems to reduce losses due to partial shading caused by nearby trees. The PV modules are fixed to a galvanized steel support structure, similarly to that of the rest of the façade.

Literature:
N. Martín-Chivelet, J.C. Gutiérrez, M. Alonso-Abella, F. Chenlo and J. Cuenca. Building retrofit with photovoltaics: Construction and performance of a BIPV ventilated façade, Energies 2018, 11, 1719; doi:10.3390/en11071719

8.04/05. Southwest view of the building before and after the renovation.

8-06. Renovation work details: mounting the PV modules.

8-07. Supporting structure and fixation details behind the PV modules.

8-08. Renovation work finished.

8-09. CIEMAT office renovation with BIPV cladding.

Director of the Renewable Energy Division Enrique Soria:
One of the areas of activities of the Division of Renewable Energy at CIEMAT is the Energy Efficiency in Building and the Integration of Renewable Energy, and specifically the Integration of Solar Photovoltaic Energy in Buildings (BIPV). New research projects are being carried out in this field, seeking new materials, thin-film cells, transparent modules etc. that allow better architectural integration and a greater contribution to electricity generation in buildings.

To strengthen the knowledge in this field, increase public dissemination and contribute to the application and improvement of self-consumption regulations, it was agreed by the management to address this project of incorporating a PV generation system into the process of renovating building 42, the headquarters of the Renewable Energy Division.

Installer Javier Pérez:
The PV system was provided with the "zero injection" device that prevents PV electricity from being dispatched to the electric power grid outside the building, in compliance with the Spanish legislation at the time of the renovation. The device monitors the electrical network and photovoltaic inverters at all times to modulate photovoltaic production in relation to electrical consumption in order not to send electricity to the grid.

8-10. Responsible renovation team.

8-11. CIEMAT office renovation with BIPV cladding.

Finance

There were no subsidies or economic incentives, but the installation saves energy consumption from the grid: it is a 100 % self-consumption case. The modules are standard with high energy efficiency, with a cost of 1.10 €/Wp. The total cost of the installation, including maintenance and reposition of the PV inverters (once in 30 years), is 2.70 € /Wp. Discounting the cost saved on a conventional façade, the net cost of the BIPV installation becomes 1.84 € /Wp.

Lessons learned

This is an example of an inexpensive, easy-to-implement, good architectural solution for building retrofit with standard PV modules integrated into a new ventilated façade. The effect of shadowing caused by the nearby trees may be significant, so if this cannot be avoided, the system should at least be divided into different sub-sections to reduce energy losses.

Detailed cost of the BIPV building renovation	
PV Modules	*€ 29,500*
Supporting structure	*€ 10,400*
Inverters + control equipment	*€ 10,300*
Engineering + installation	*€ 7,000*
Cabling	*€ 4,800*
Maintenance and reposition	*€ 14,000*
Total cost	*€ 76,000*
Energy cost (30 years) (€/kWh)	*0.127*
Cost per unit of peakpower (€/Wp)	*2.70*
Cost per unit of area (€/m^2)	*€ 520*
Saved cost (conv. façade)	*€ 24,200*
Net cost	*€ 51,800*
Net energy cost (30 years) (€/kWh)	*0.086*
Net cost / unit of peak power (€/Wp)	*1.84*
Net cost / unit of area (€/m^2)	*354*

Azurmendi Restaurant, Biscay (ES)

Project data			
Project type	New construction		
Building function	Restaurant		
Integration system	Glass roof		
Location	Barrio Legina, s/n Larrabetzu . Bizkaia		
Architect	Naia Eguino	Year	2012
BIPV system data		**Producer data**	
PV modules s	Insulated low-e 20 % + 10 % transp.(L vision)	Producer	ONYX SOLAR ENERGY SL
Solar technology	Thin-film amorphous silicon	Address	C/ Rio Cea 1-46 (05004), Ávila
Nominal power	21 kWp	web	www.onyxsolar.com
System size	267.7 m^2 (active area), 283.6 m^2 (total PV area)		
Module size	1628 mm x 1309 mm / 2653 mm x 1309 mm		
Orientation	Southwest	Author/editor	N. Eguino, E. Rico, A. Sanchidrián and
Tilt	Vertical façade (90°) and skylight (6°)		J. M. Jiménez

Azurmendi Restaurant, Biscay (ES)

9-01. Main lobby with BIPV roof from the inside.

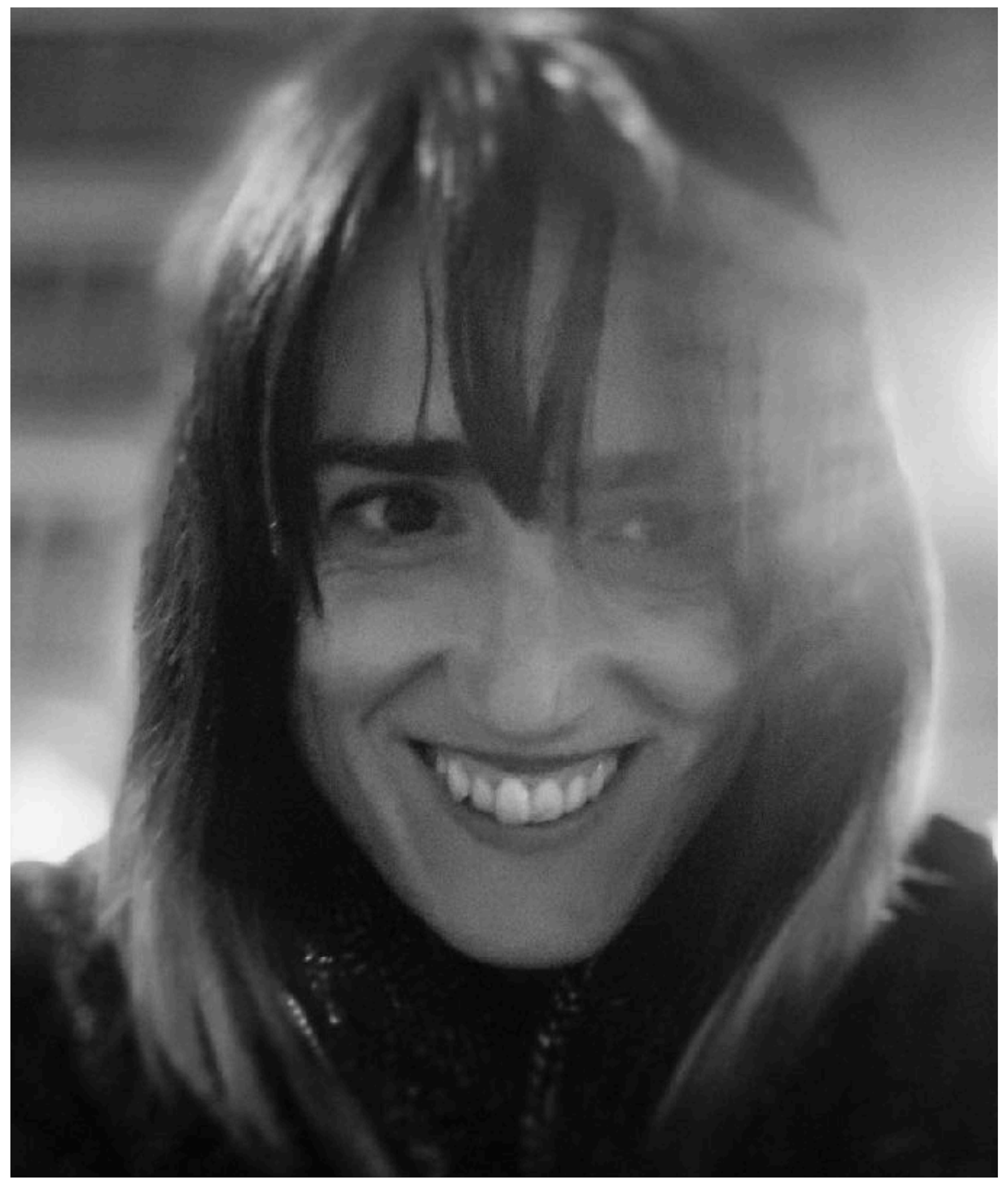
9-02. BIPV roof structure.

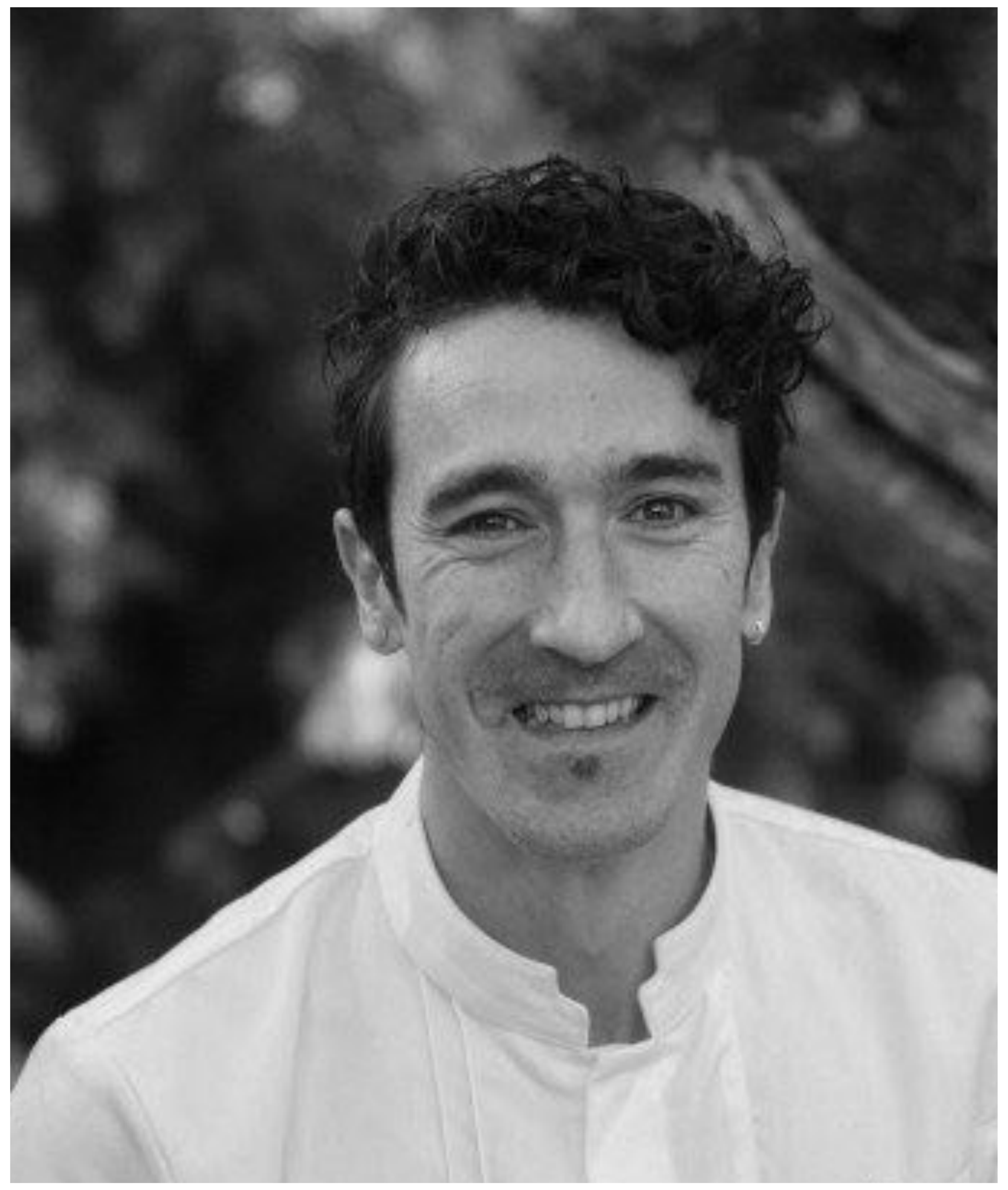
Interview with Naia Eguino (architect) and Eneko Atxa (Michelin star chef)

How did your relationship client-architect starts?
We have known each other since 2002 more or less. When we started to design the first building of Winery Gorka Izagirre, on the top floor there was the restaurant where Eneko was going to start his own career. Eneko and I were the same age. Very young. There we started a friendship between the three of us. Some years later, when they came to see me with the proposal for a new building, the ideas came easily, because we had evolved together. I knew much about their evolution in the kitchen and their steadily increasing interest in natural, ecological, sustainable products. And I, as an architect, had also been working in that direction for years. This is how the building was born.

When was the decision to use photovoltaic modules taken?
The building is a combination of three bodies: greenhouse, dining room and kitchen. The heart of everything is the kitchen. Access to the building is through the greenhouse, a large glazed hall with a lush garden. This space creates a problem in summer since it can get very hot so that a great amount of energy would be necessary to cool it. We started to study how to prevent overheating, and that point is when using photovoltaic cover glazing emerged, because it helps electricity generation and shading together. Thus photovoltaic energy was integrated into the building.

What has the PV system added to the building?
It has helped to address several aspects. The aesthetic, as the architectonic integration is absolute. The energy-related because the PV system generates electricity for the lighting of the building. And, as I said before, it helps to shade the space.


9-03. Naia Eguino.


9-04. Eneko Atxa.

9-05. Entrance atrium, roof from the inside.

9-06. Indoor greenhouse.

9-07. Entrance atrium next to the kitchen.

Building / system integration

Decision-making.

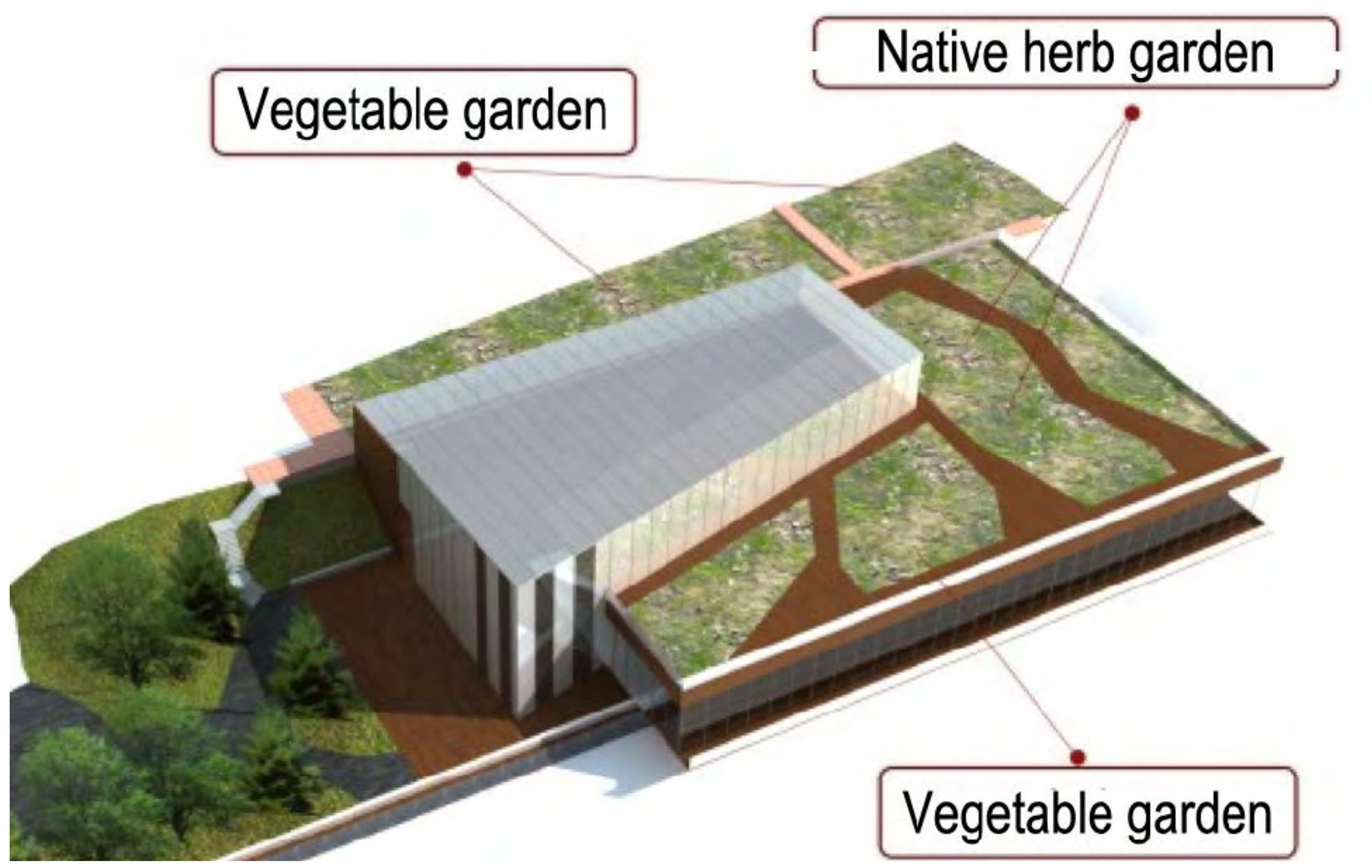
This project was conceived as an evolution of another existing building where Chef Eneko Atxa started his career along with the Gorka Izagirre family winery. The need to change the building arose from his evolution as a cook. Corresponding to his ecological aspirations as a cook, the building approach was a bio-climatic building with a greenhouse where the cooking ingredients are what is planted there. It is designed as a sustainable building in terms of water, materials and energy.

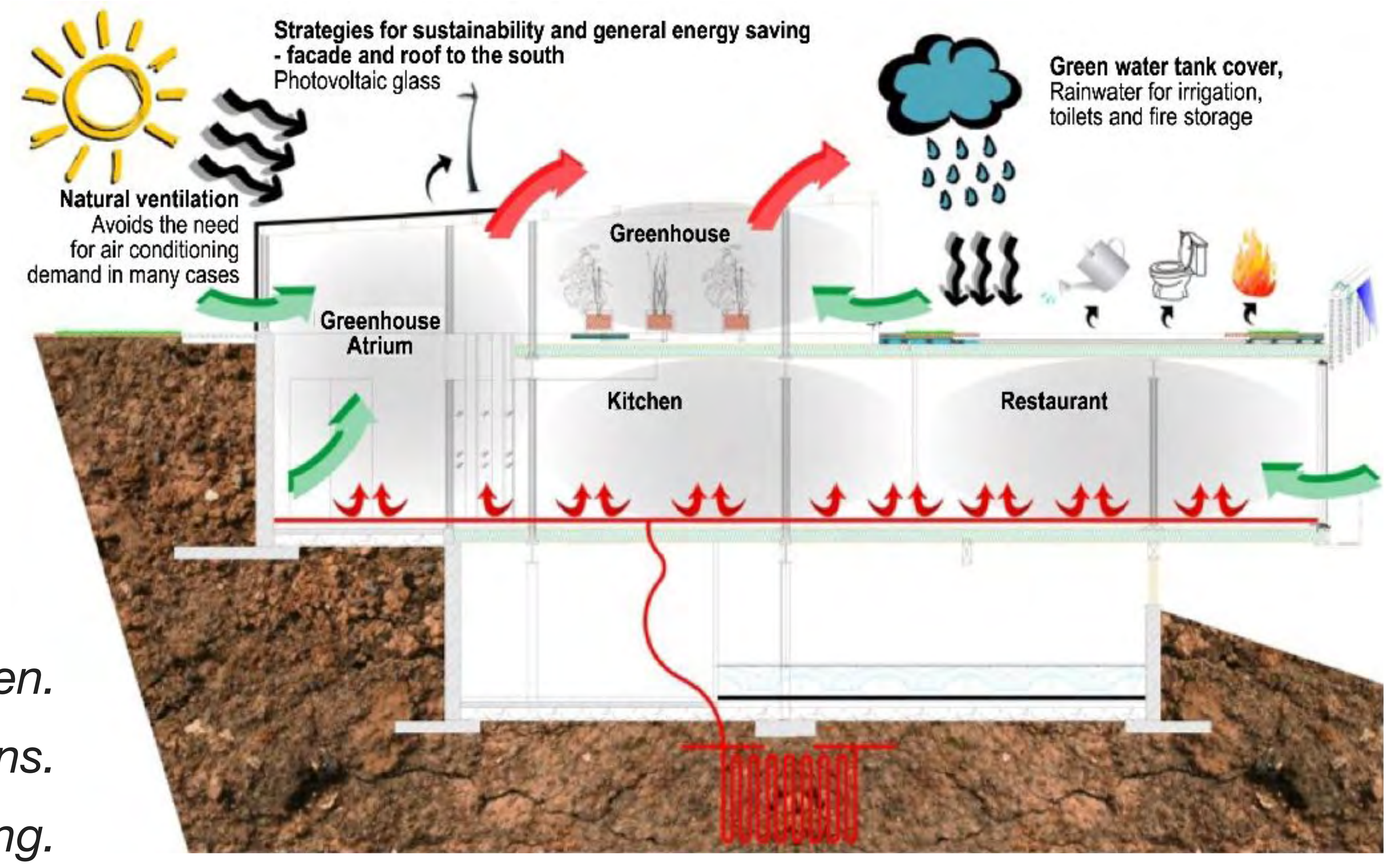
LEED certification

The building has been created with an educational mission since its initial design. It was intended to show the customer not only the chef's cuisine but the way to build sustainably. This is why the equipment of the photovoltaic system is exposed in the atrium of the building behind glass where the customer can see it. It has been certified LEED Silver, considering all the areas that influence energy in the building, such as offering employees options to arrive by bicycle and to take a shower later, creating an area for recharging electric cars, controlling the levels of natural and artificial lighting, and, of course, using renewable energy sources.

The building uses different renewable energy systems such as geothermal energy, passive solar energy and photovoltaic solar energy. Almost 100% of the building is acclimatised by geothermal energy. Eighteen wells with a depth of 118 m each have been constructed for this purpose.

Other aspects are: the materials used are recycled or recyclable. There is a green cistern-roof where rainwater is recycled for irrigation and WC cisterns, which, in addition, serves as a very good insulator.

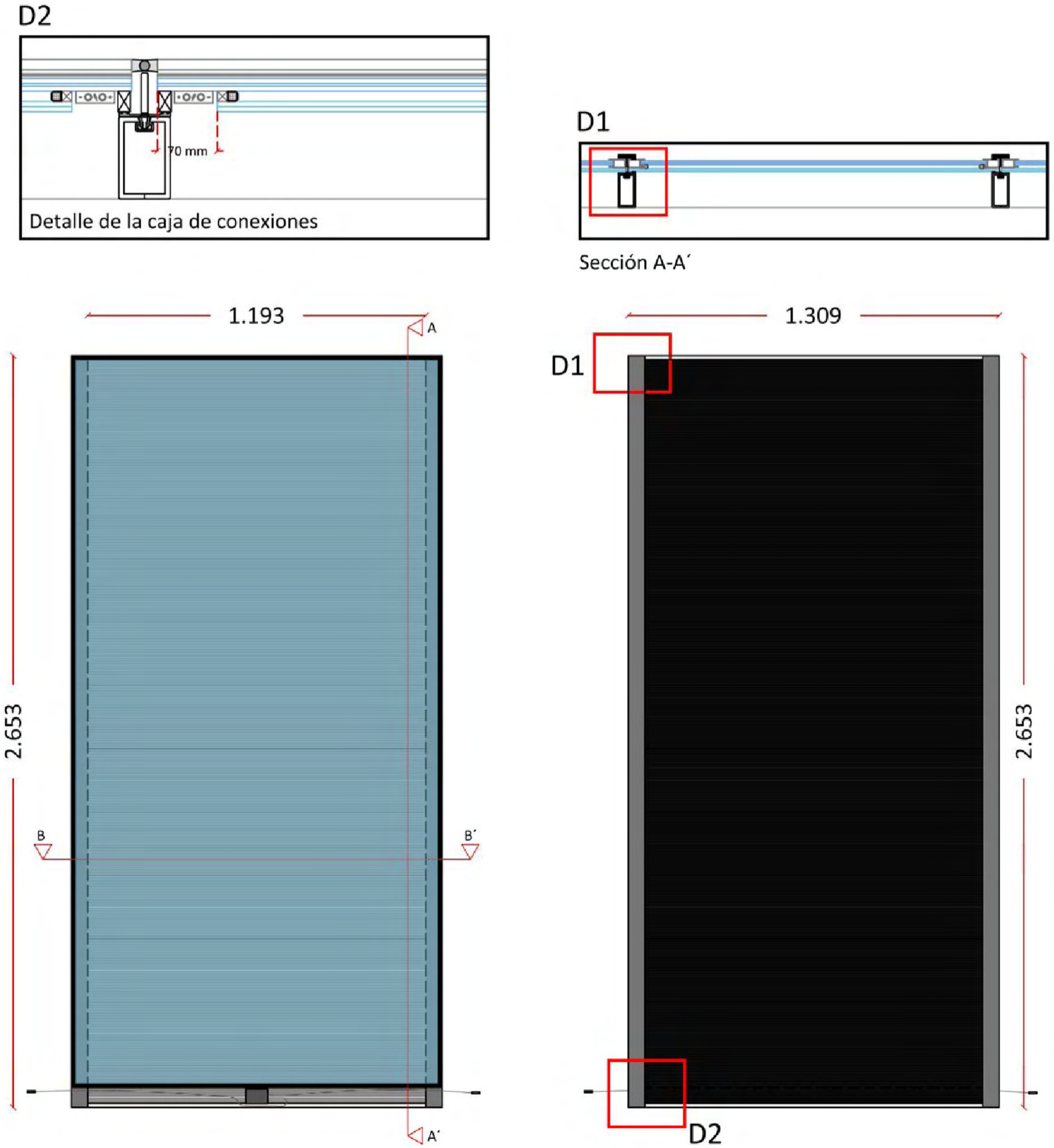




9-08. South façade with PV modules in the vegetable garden.
9-09. The underlaying idea: a building surrounded by vegetable gardens.
9-10. Cross-section through the bio-climatic building.

9-11. Glass and BIPV roof.

9-12. BIPV roof structure.



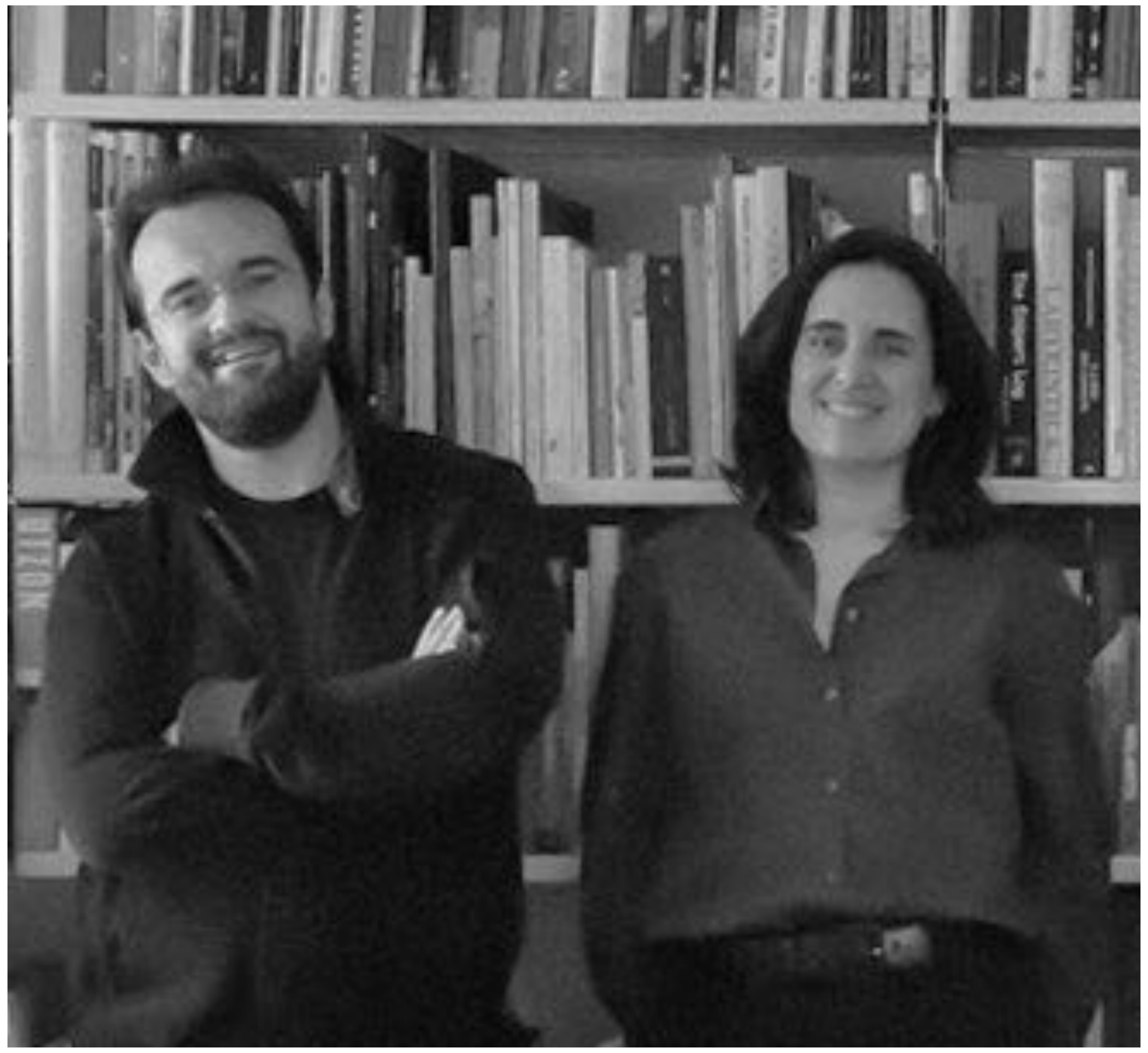
9-13. BIPV modules from ONYX

San Anton Market, Madrid (ES)

Project data			
Project type	Refurbishment		
Building function	Food market		
Integration system	Glass roof		
Location	Madrid		
Architect	QVE Architects	Year	2011
BIPV system data		**Producer data**	
PV modules	Customized BIPV double low-e glass	Producer	ONYX SOLAR ENERGY SL
Solar technology	Thin film amorphous silicon (20%	Address	C/ Rio Cea 1-46 (05004), Ávila
Nominal power	6.5 kWp	web	www.onyxsolar.com
System size	168 m^2, 54 modules		
Module size	2536 x 1147 mm and 2668 x 1147 mm		
Orientation	2º Southwest		
Tilt	10°	Author/editor	E. Rico, A. Gallego

San Anton Market, Madrid (ES)

10-01. BIPV roof from the inside.



10-02. Ms. Ana María Montiel Jiménez, Architect of ATARIA (r).

Interview with Ms. Ana María Montiel Jiménez, Architect of ATARIA architectural firm (QVE-architects)

What did you see in ONYX SOLAR photovoltaic glazing that made you decided to incorporate it into the design of the project?

Ms. Ana María Montiel Jiménez: The photovoltaic glazing allows two functions to be combined: the possibility of illuminating an interior space, while having a solar installation. In our case, the skylight in which the installation was placed is the backbone of the project, so it was also wanted to add a pedagogical function, making the visitors aware of the need of using renewable energy.

Evaluating those criteria that led you to select this photovoltaic glazing. What is the degree of satisfaction obtained based on the result achieved?

Ms. Ana María Montiel Jiménez:. The degree of satisfaction is high since the main function was fulfilled.

Could you quantify any significant data as a result of the integration made?

Ms. Ana María Montiel Jiménez: Since managers did not decide to monitor the use of the energy obtained, no data can be provided in this regard. On the other hand, personally, the main objective of having a photovoltaic installation as a fully integrated element in the building was an absolute success, as the qualities of double functionality sought were provided.

Over the years. How do you rate the integration made? Why would you recommend a similar solution for other projects?

Ms. Ana María Montiel Jiménez: The integration is absolutely satisfying. We believe that use of renewable energy is a key objective in society in general, and architecture in particular, and photovoltaic glazing allows it to be incorporated in a natural way in necessary elements of the interior space.

Building / system integration

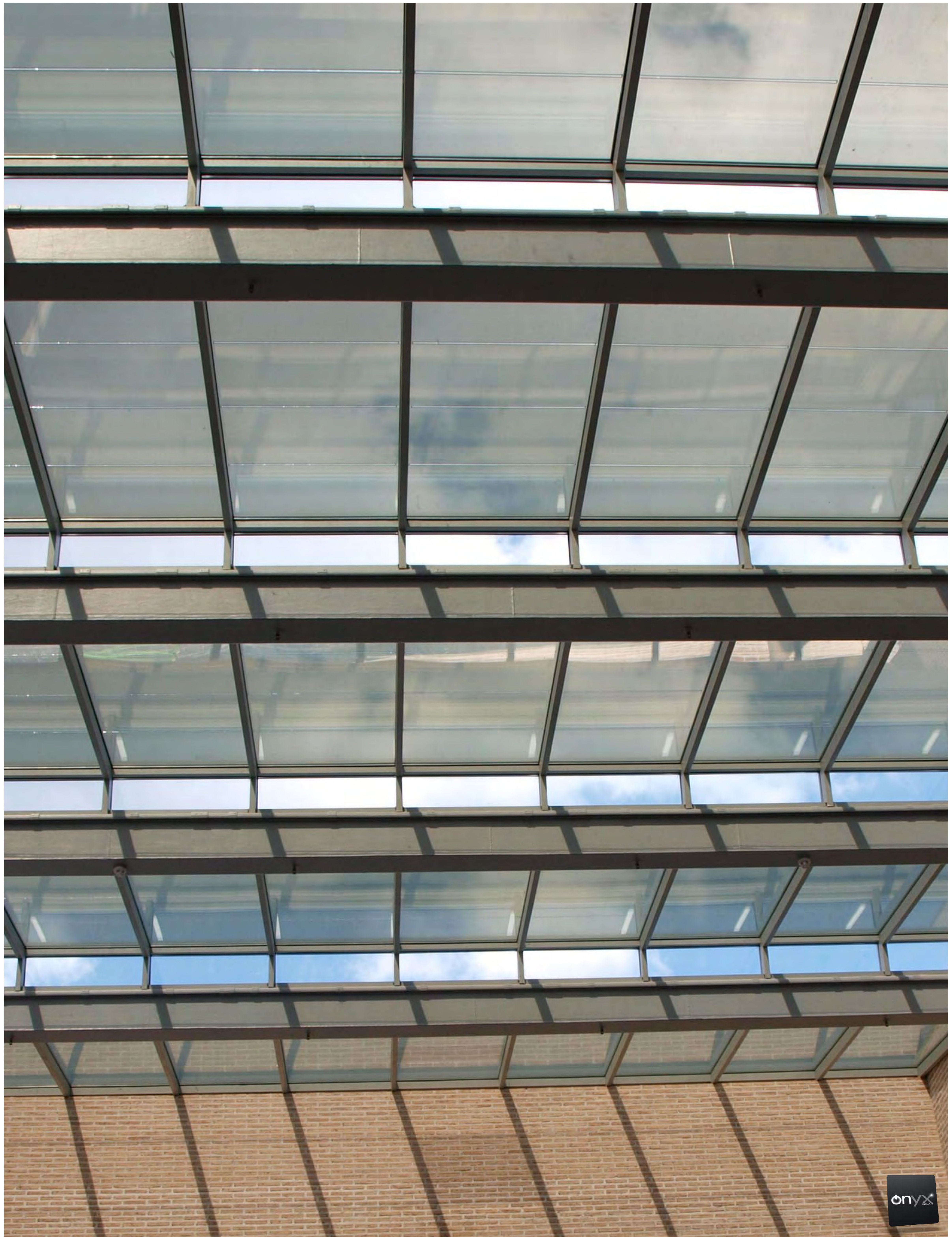
Formal integration
This project is part of the refurbishment of San Anton Market, located in the centre of Madrid, where a 168 m^2 skylight, comprised of transparent low-e photovoltaic glazing, has been completely integrated into the building.

Energy integration
The system enables the generation of electricity in situ, while providing multi-functional bioclimatic properties such as the filtration of solar radiation, and at the same time enhancing interior light and providing thermal and acoustic insulation thanks to its double glazing.

Technological integration
The photovoltaic glazing employed is made of amorphous silicon, with a semi-transparency degree of 20% (L vision), and the total installed power capacity is 6.5 kWp. This photovoltaic skylight generates over 7,700 kWh per year and prevents the emission of 5 tons of CO2. For this reason, it has been selected as a sustainable project of reference by the European Commission.

10-03. View from the outside. BIPV modules were installed with a small slope to facilitate water drainage.

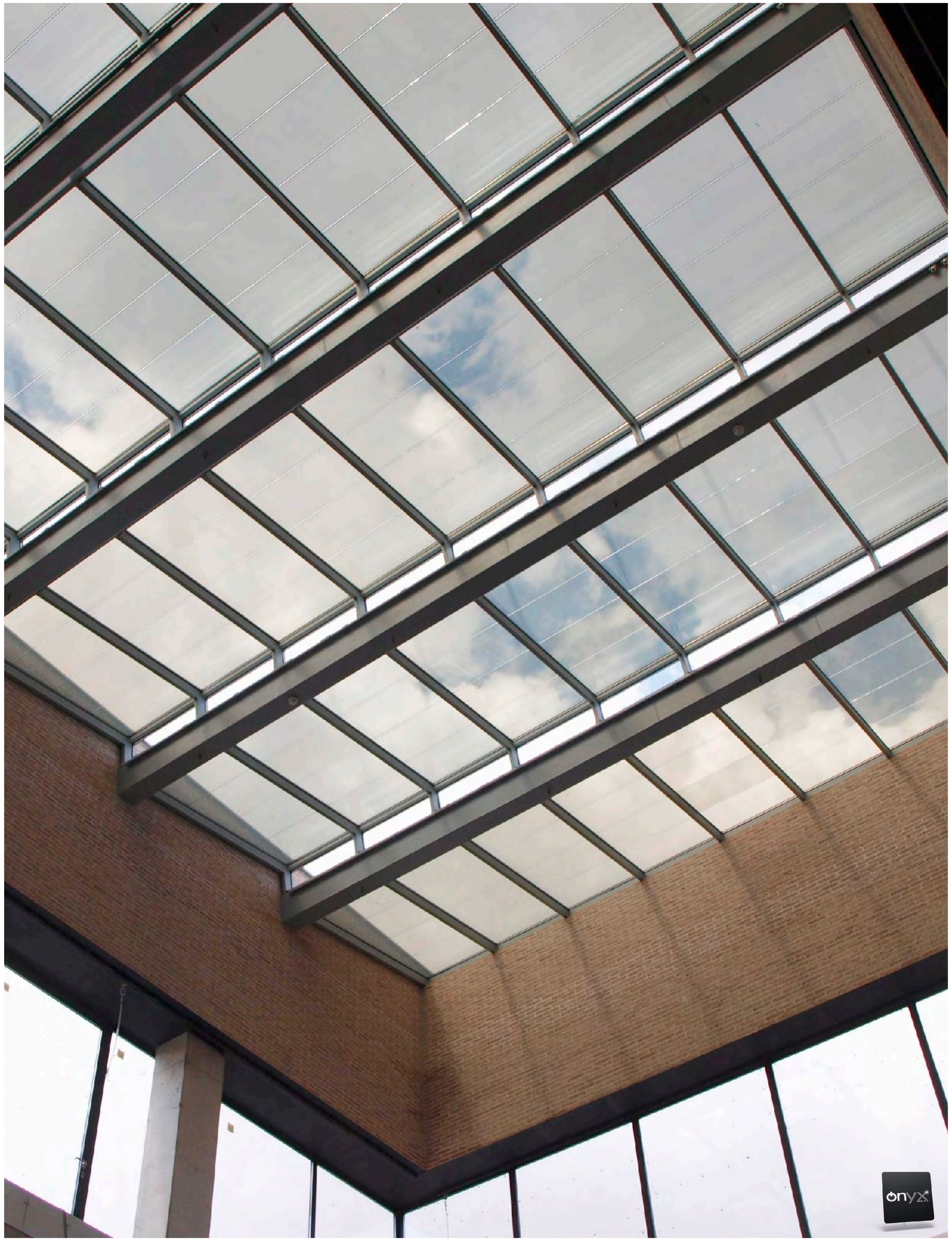
10-04. Interior view. With a medium degree of transparency, the BIPV modules transmit light to the interior while retaining good electrical performance.



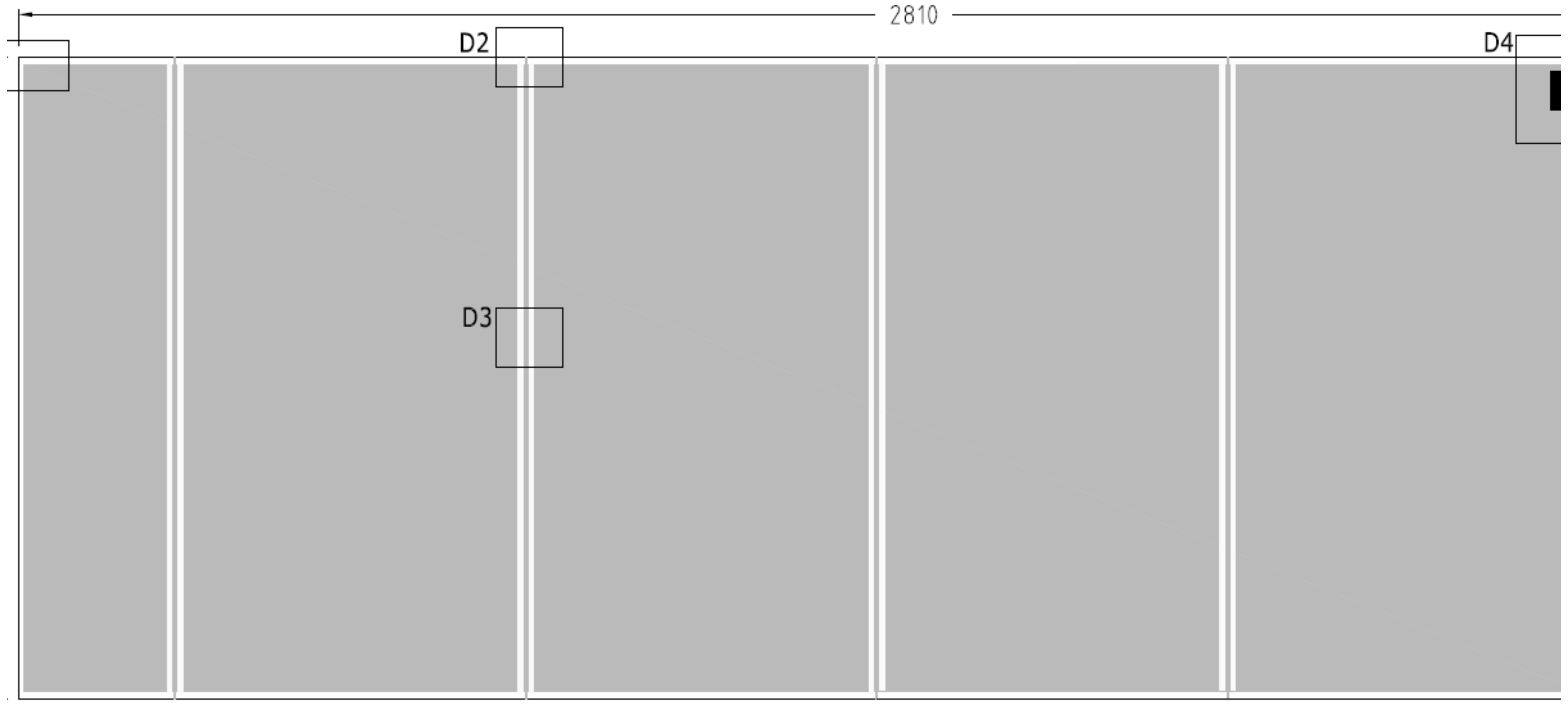
10-05. Junction boxes and wires are hidden inside the supporting structure to optimize the aesthetic of final installation and reduce the visual impact of the electric elements.

10-06. ONYX solutions have a modern appearance similar to conventional glazing solutions which facilitate their integration in urban environments.

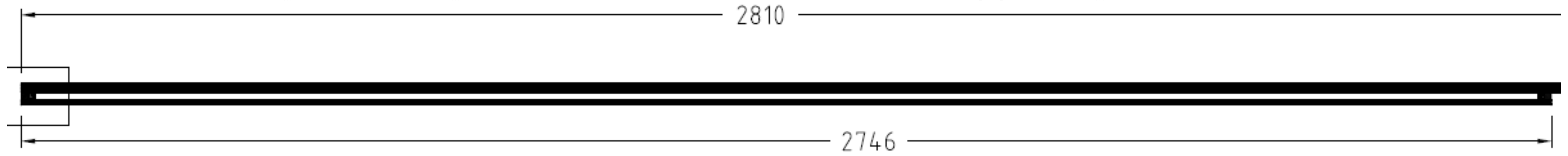
10-07. Without affecting the electricity generation, Onyx Solar Low-E photovoltaic glass reduces the infrared (90%) and ultraviolet radiation (99%) compared to with conventional laminated glass.

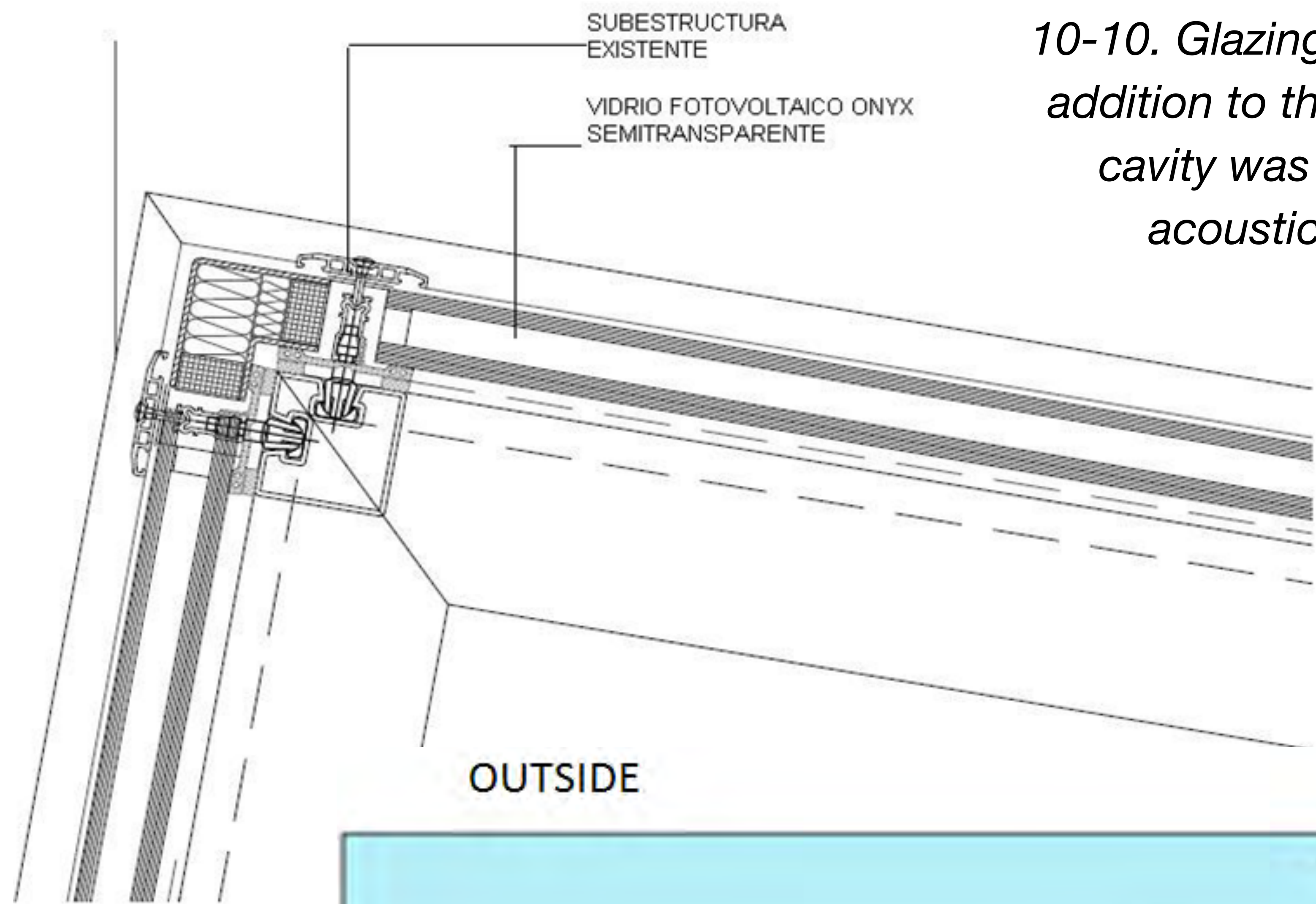


10-08. Low-E photovoltaic glazing has a Solar Heat Gain Coefficient (SHGC) that is much lower than that of conventional laminated glazing. A low SHGC value is critical for thermal comfort, particularly for hot climates such as Madrid.

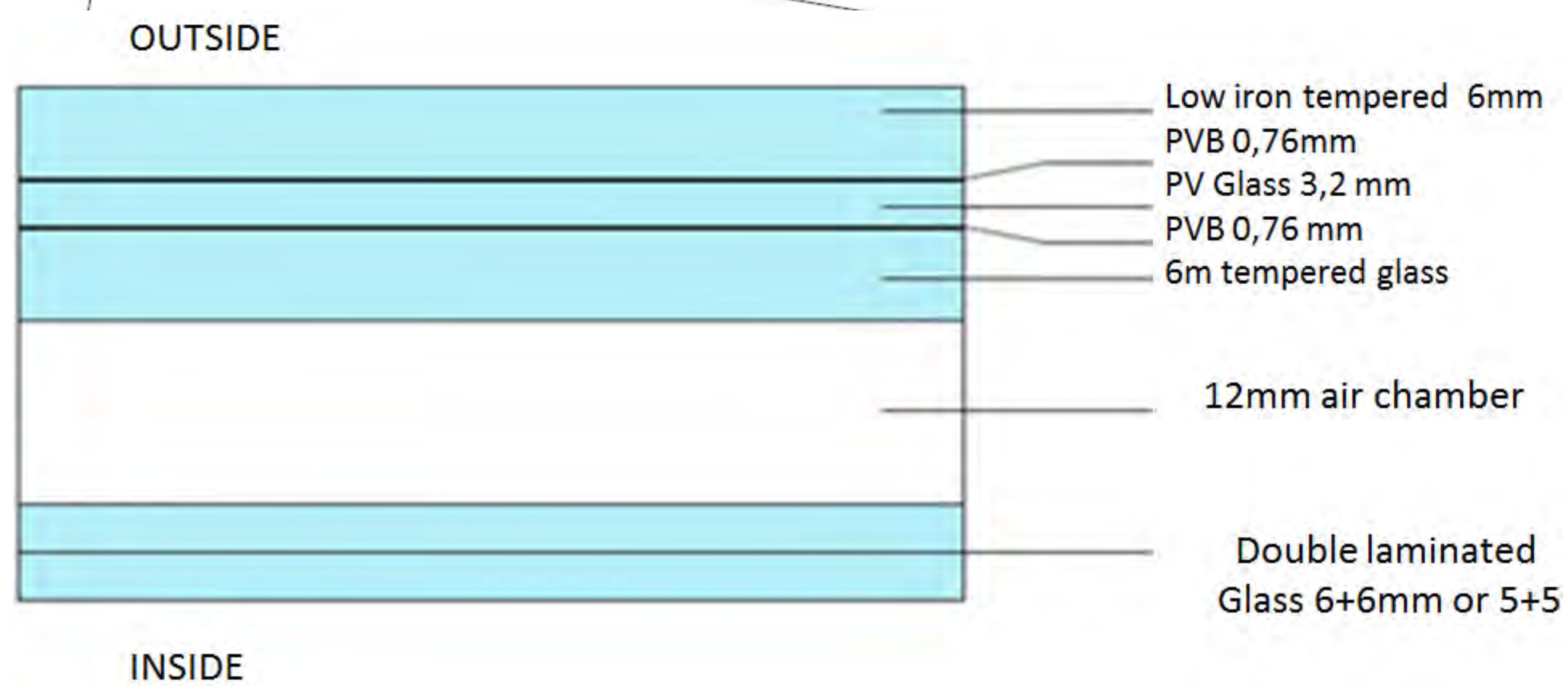


10-09. Details of glass configuration and installation on the supporting structure.





10-10. Glazing configuration of the PV glazing. In addition to the low-E PV glass, a 12 mm air-filled cavity was chosen to increase the thermal and acoustic insulation of the complete module.



ONYX SOLAR Architect Mr. Ángel Gallego

The San Anton Market Project was a technical challenge for Onyx Solar since it was the first one that we executed using photovoltaic glazing with an insulating gap between two panes (IGU, Insulated Glazing Unit). It created a twofold challenge as it was necessary to provide a solution to the exit of the wiring from the rear part of the photovoltaic glazing through the connection box and, at the same time, to find a technical solution to hide the wiring that interconnects the glazing units with each other and the strings that reach the inverters.

The design of the skylight in a saw-tooth pattern was the most suitable solution to position the junction boxes on the photovoltaic glazing offsets. The work carried out by the architectural company's team, the construction company and Onyx Solar technical team was completely coordinated during the execution of the project, which allowed agile solution of any small setbacks that occurred during the different project stages.

The final result of the skylight was satisfying. It was possible to achieve the goals of integrating 100% photovoltaic glazing with an insulating air gap and allowing the light to pass into the building in a controlled manner. The integration with the building is so satisfactory that the employees and users of the Mercado de San Anton building are unable to perceive that part of the energy they consume is being produced cleanly "over their heads" thanks to the sun.

10-11/12. Since its refurbishment, Mercado de San Anton has become a local meeting point including a market of perishable goods, bars and restaurants and it has enhanced the attractivity of one of the most representative districts of Madrid

10-13. Lucernario Mercado San Anton - sunlight effect

Although the initial cost of this skylight could be higher if it is compared to conventional solutions because of the photovoltaic and electrical components, economic viability is achieved due to the capacity of the PV glazing to generate free electricity from solar light and the passive properties that reduce climate control loads and HVAC demands. The total cost of the skylight was calculated to be 700 €/ m^2. A feasibility analysis was done on the basis of total cost and an estimation of electricity generation per year of about 7,748 kWh. Under these conditions, the energy price was estimated to be about 0.02 €/kWh. Besides, the use of the BIPV solutions could lead to a reduction of 34% in HVAC energy demands with 55% as the internal rate of return and a payback less than 2 years.

Detailed cost

Insulated PV glass units	400 €/m^2
Structure	240 €/m^2
BOS	60 €/m^2

Enzian office, Bolzano (IT)

Project data			
Project type	New construction		
Building function	Office		
Integration system	BIPV in façade and balustrade		
Year - Location	2012 - Via Ressel 3, 39100 Bolzano		
Architect	Arch. Zeno Bampi		
BIPV system data		**Producer data**	
PV modules	Custom-made	Producer	Arnold Glas GmbH
Solar technology	Thin-film amorphous silicon	Address	Alfred Klingele Str. 15, 73630 Remshalden (DE)
Nominal power	100 kWp	web	www. arnold-glas.de
System size	3,700 modules, 2,340 m^2		
Module size	1,020 x 626 mm		
Orientation	West, south, east façade		
Tilt	90°	Author/editor	Laura Maturi, Jennifer Adami

Enzian office, Bolzano (IT)

11-01. BIPV façade.

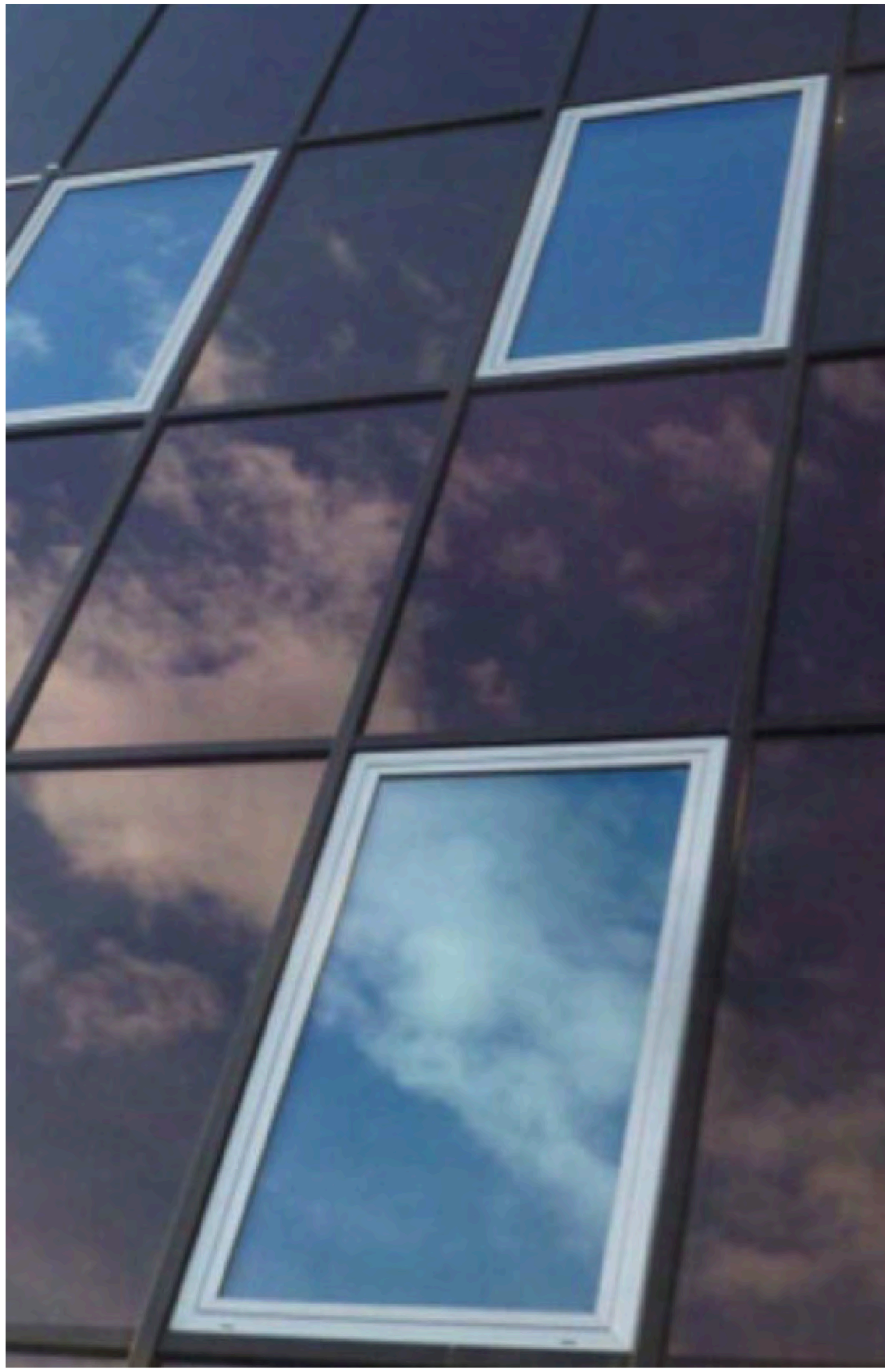
Interview with Arch. Zeno Bampi

Challenges

Enzian Office represents a real pioneer in the Trentino Alto Adige region, since no other similar buildings had previously been realized with integration of photovoltaic panels in the glazed façade. From the very beginning, the client was inclined towards the innovation. We rejected the traditional glazed façade, which usually is a cause of overheating. We decided to create a multi-functional surface that not only generates electricity but also shades the internal sites. The semi-transparency of the glazed PV modules controls the incoming sunlight and prevents the excessive building overheating. People felt well inside the building. There is enough light and no glare, and people can see everything outside.

Aesthetics

The building has an extremely visible position, close to major traffic routes. It is a large block with dark uniform surfaces, like many other constructions nowadays. The BIPV modules determine the visual appearance of the building but they blend in it so that people do not notice the PV presence.



11-02. External view of the modules' metal framing system.

11-03. External view of the BIPV façade.

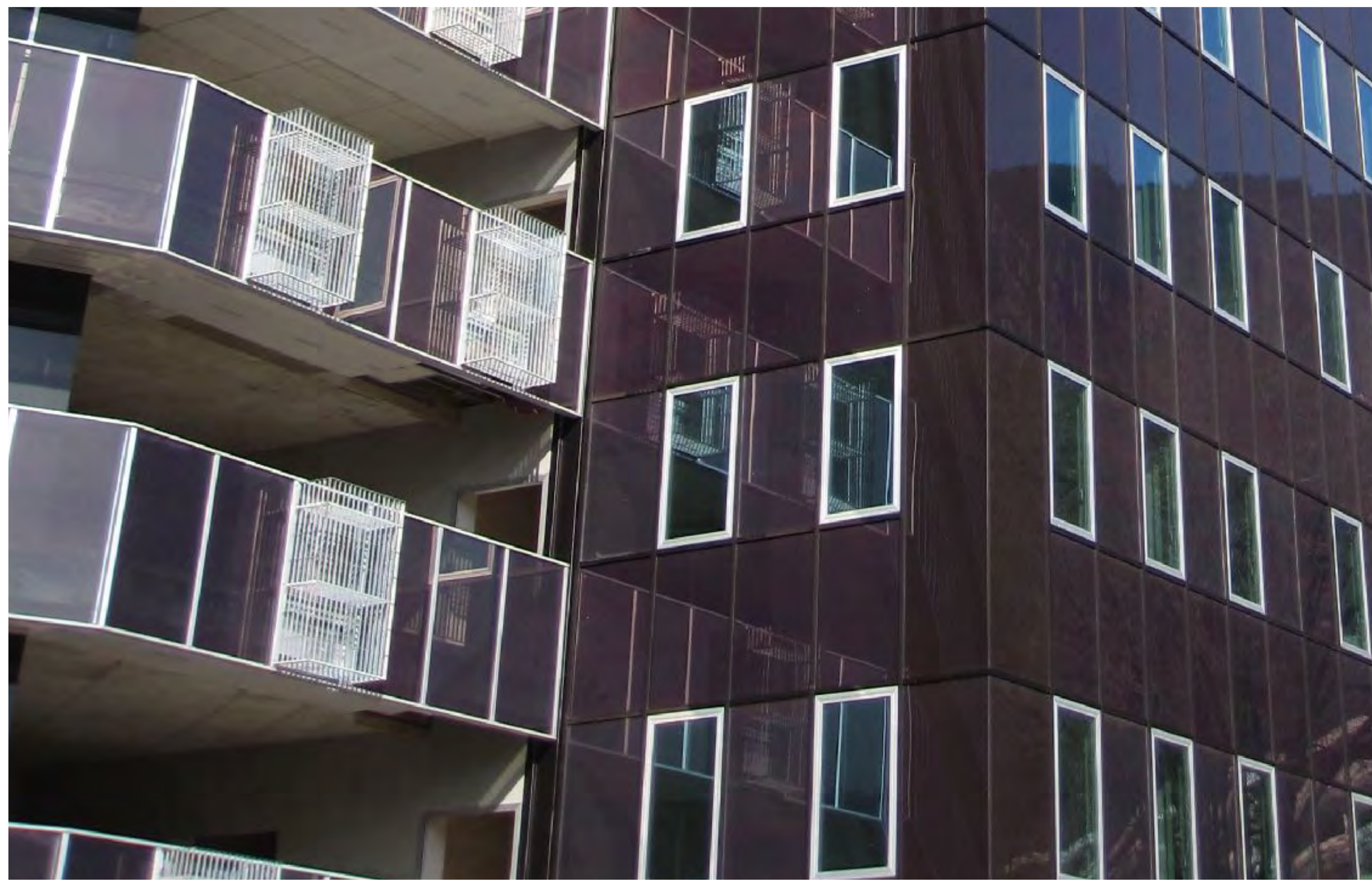
Decision-making

The building was designed to be self-sufficient with regards to energy; hence, the decision to integrate a photovoltaic plant. The wide building façades were covered as much as possible with PV modules in order to maximize the electricity generation exploiting most of the available solar radiation. Amorphous silicon was chosen instead of crystalline silicon, because of its uniform shading effect for the interior and its uniform appearance on the exterior (Energytech Srl). Additional PV modules were applied to the building roof in order to increase the supply of electricity in the building.

Process

The building construction was commissioned by the PSZ di Gral Srl. The design process involved several stakeholders, including Arch. Zeno Bampi and Ind. Eng. Franz Steiner, building designers, Eng. Sigfried Pohl, responsible for the structural evaluation and works supervisor, and Energytech Srl for the thermal plants.

Pohl Immobilien is the building owner.



11-04. The building balustrades also are made of glass BIPV modules.

11-05. Enzian Office BIPV system: the modules replace opaque parts of the façade (horizontal bands below windows) and semi-transparent sections (horizontally between windows).

Building / system integration

Formal integration
Enzian Office is a 10-storeys building located in the industrial zone of Bolzano. The whole building is covered with photovoltaic modules integrated into the glazed building façade. The PV modules are made of amorphous silicon that homogenizes the external surfaces, so that the difference between opaque and semi-transparent façade parts is not recognizable. The integrated PV skin makes the 'sustainable design' highly visible from outside.

Energy integration
The building is certified CasaClima Gold. The PV system integrated into the building envelope, together with modules placed on the roof, produces around 113 MWh/year, supplying enough energy to meet the building heating and cooling needs using a reversible heat pump and a pellet heating system. The system is grid-connected, so the excess energy is fed into the power grid.

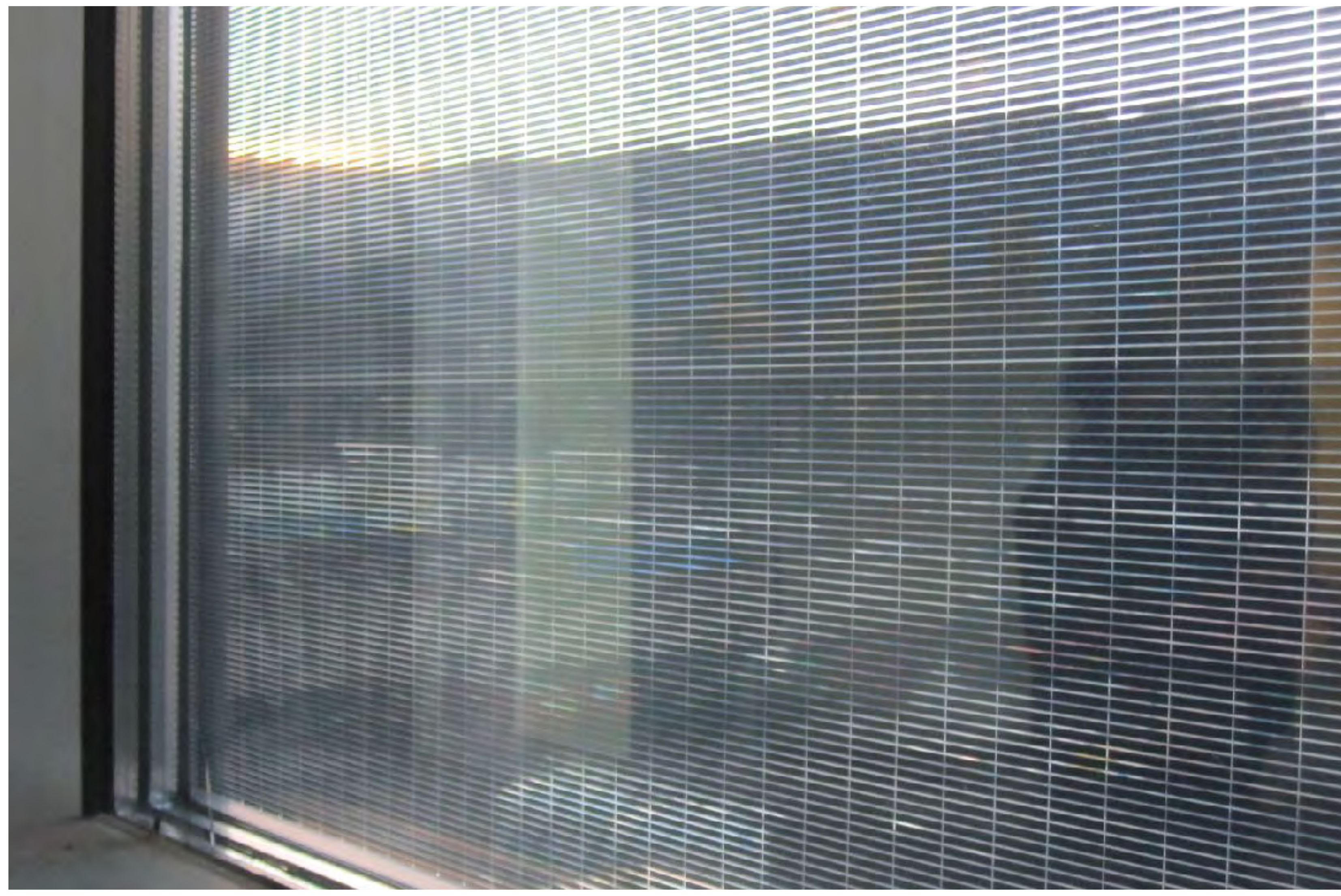
Technological integration
Depending on the solar exposure of the building façades, either double or triple insulating glazing with amorphous silicon modules or opaque laminated glass is used. The photovoltaic modules (Voltarlux) are designed on the basis of Schott Solar's ASI THRU thin-film technology consisting of silicon tandem cells (3 mm) on a glass substrate. Some modules replace the semi-transparent façade part. The interior is protected with laminated safety glass. The gap between the glass panes is filled with argon for thermal insulation. Other modules replace the opaque façade part with an insulating layer behind them. The gap between the modules and the insulation is 50 mm and is closed at the bottom and top. Cables are contained within the framing system.

Finance

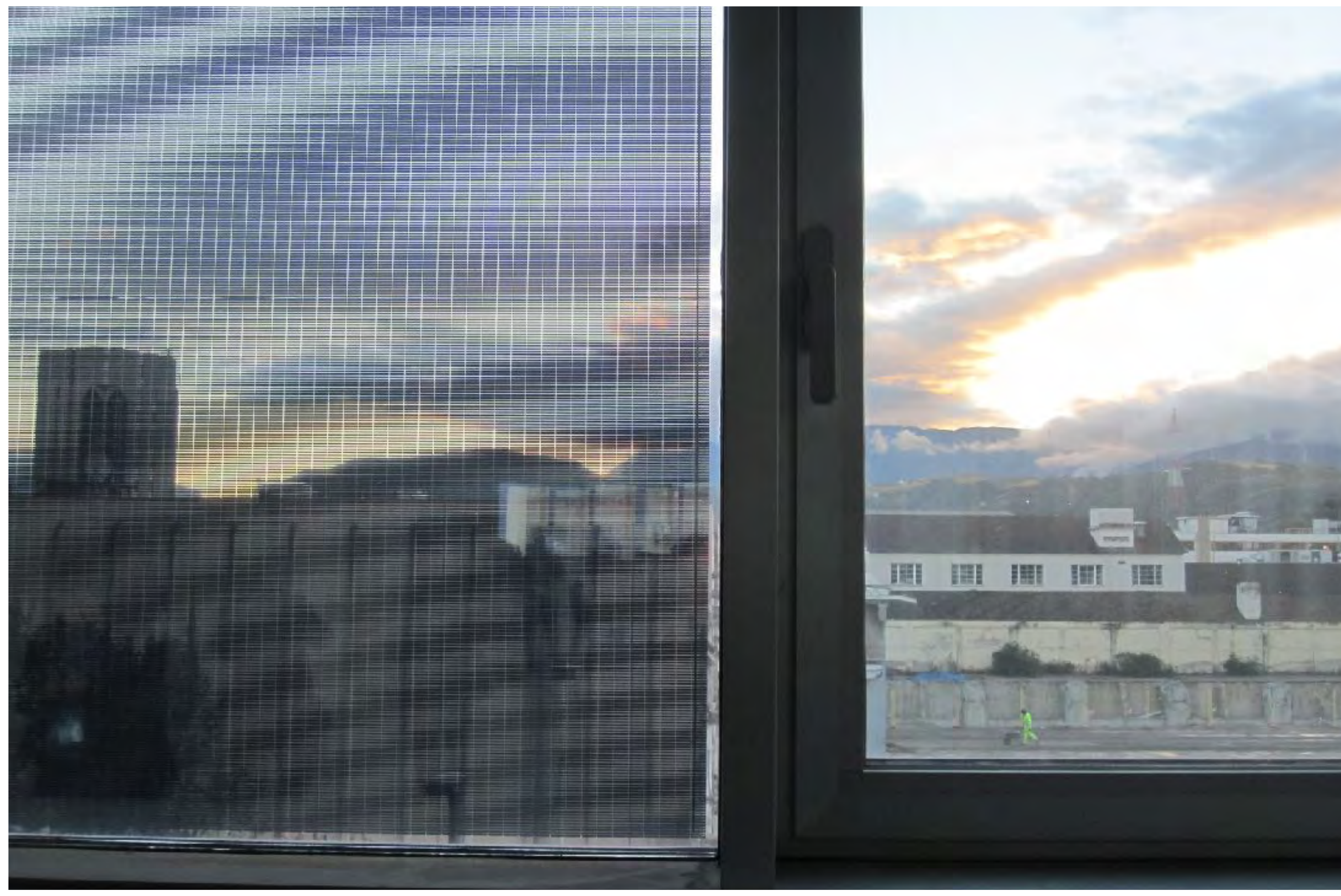
Most of the Enzian Office is covered with photovoltaic panels for most. Moreover, the panels are customized. As consequence, the whole BIPV system cost was quite high. Nevertheless, the client immediately agreed to install such an expensive system, as he was motivated to achieve high sustainability targets.

Lessons learned

The PV modules are integrated into different building components, providing examples of how the PV might be used in place of traditional building materials. The PV replaces the semi-transparent parts, the insulating windows, the external parapets and the external cladding. In the semi-transparent part, it is used for solar control without the need for additional shading provisions that would have increased the costs. Moreover, the amorphous silicon texture produces a special lighting scenario, a uniform shading effect that does not disturb the office's users. The light-controlling function of the photovoltaic cells is added to the insulating function of the glazing system, highlighting the multifunctional feature of the BIPV technology. Regarding the BIPV system design, one of the main challenges reported by the designer is related to the strict fire-safety regulations, which need to be respected in the façade design (Energytech Srl).



11-06. Detailed view of the semi-transparent modules' texture.



11-07. Sun-shielding effect of the BIPV modules.

NTT Aoba Dori Building, Sendai (JA)

Project data			
Project type	New construction		
Building function	Telecommunication business office		
Integration system	BIPV as façade cladding		
Location	2-8-25 Ichibancho, Aoba-ku, Sendai City,		
Architect	NTT Facilities Inc.	Year	2013
BIPV system data		**Producer data**	
PV modules	Custom-made	Producer	LIXIL Corporation
Solar technology	Multi-crystalline Silicon	Address	2-1-1 Ojima, Koto-ku, Tokyo
Nominal power	20 kWp	web	www.lixil.com
System size	618 modules, 423 m^2		
Module size	1790/1223/1414 × 302 mm		
Orientation	South		
Tilt	90°	Author/editor	Hisashi Ishii

NTT Aoba Dori Building, Sendai (JA)

12-01. BIPV façade.

IInterview with NTT Facilities Inc. , project manager Takeo Sakamoto, chief architect Hiroaki Yamayoshi, architect Hisashi Hasegawa, architect Masanobu Nojiri and architect, Tomohide Satou.

This project is a building within the next generation of information and communication office buildings which are planned to consolidate the call centre bases of the NTT (Nippon Telegraph and Telephone Corporation) group, located in the central area of Sendai City.
It is a building that benefits society. The project introduces seismic technology and environmental measures in balance with the provision of more than 1500 m^2 office floor area, that is optimized for the call centre business.
Its construction is a showpiece for safety and security information and is also a symbol of reconstruction after the "Great East-Japan earthquake".
The façade of this project required a large sheer wall as a design-given condition so it was difficult to include a conventional daylight aperture area.
On the other hand, because it became clear that a certain amount of solar irradiation can be gained on the southern wall, and based on the project concept of environmental architecture, the façade design with BIPV modules was proposed to the client and finally the installation of the BIPV modules on the southern façade was agreed.
The challenges of the project were to combine technical integration of each elements (building materials, PV cells, electrical wiring etc.) and the realization of the innovative design image.
Electricity generated by the façade is used in the building for the shared office area.
We received the feedback that the eye-catching façade BIPV favcade enhances the information and communication office building and is quite impressive.

12-02. Nojiri Masanobu.

12-03. Satou Tomohide.

Decision-making

The reason for the BIPV adoption were that it is a fitting façade design for the environmental concept of the project, that as a design-given condition, a large sheer wall on the southern façade is necessary, and that a certain amount of solar irradiation can be gained on the southern wall. The visible appeal of environmental architecture may enhance the company image and is appreciated publicly.

Process

At the design stage, after gathering and analysing project examples of wall-installed PV panels, the design was confirmed.
At the construction stage, intensive and frequent discussions within the joint venture between Takenaka, Daiichi, Hutech (general contractor) and LIXIL (façade contractor) achieved the final design and construction technology.

Building / system integration
Formal integration

To express the innovative character as the next generation of information and communication office buildings, a louvre type of PV modules is installed on the façade with a pattern of horizontal lines which is a design feature of the entire building. The louvre type of BIPV is installed alternately to keep continuity with the louvres of the air supply and exhaust facilities at the edge of is installed the façade.

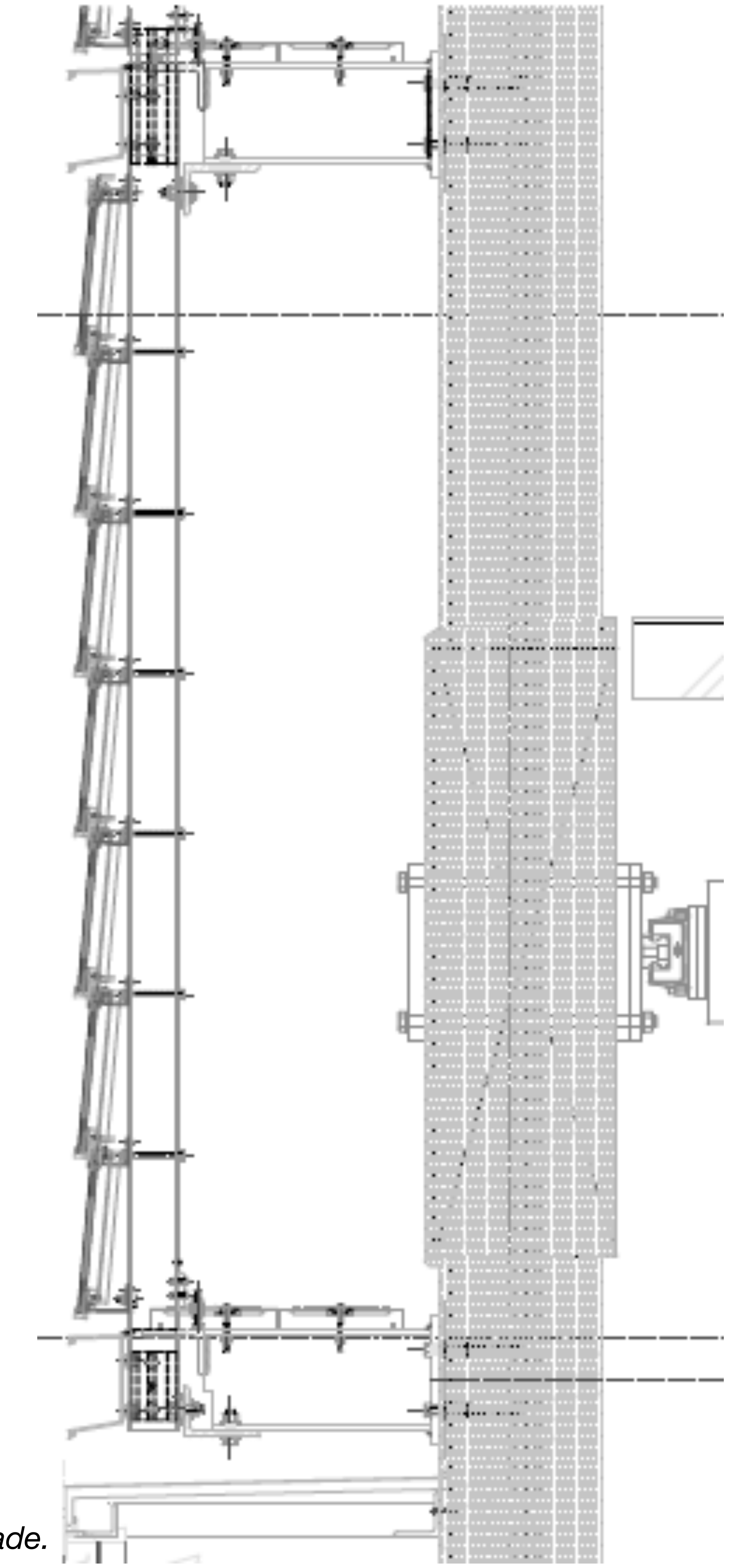
Energy integration

The balanced environmentally conscious measures are applied to each of the building materials, air-conditioning facilities and electricity facilities.
For the façade, we introduce a naturally ventilated sash system which utilizes fresh air and enables load reduction for the air-conditioning system during mild weather. The desiccant air-conditioning system which we adopted for the project controls the temperature and humidity separately, creating a more comfortable indoor-environment. For the electricity system, LED lighting is installed throughout the entire building and a 17KW PV system is installed on the roof.
The entire approach achieves the right equilibrium between reducing energy consumption and generating electricity.

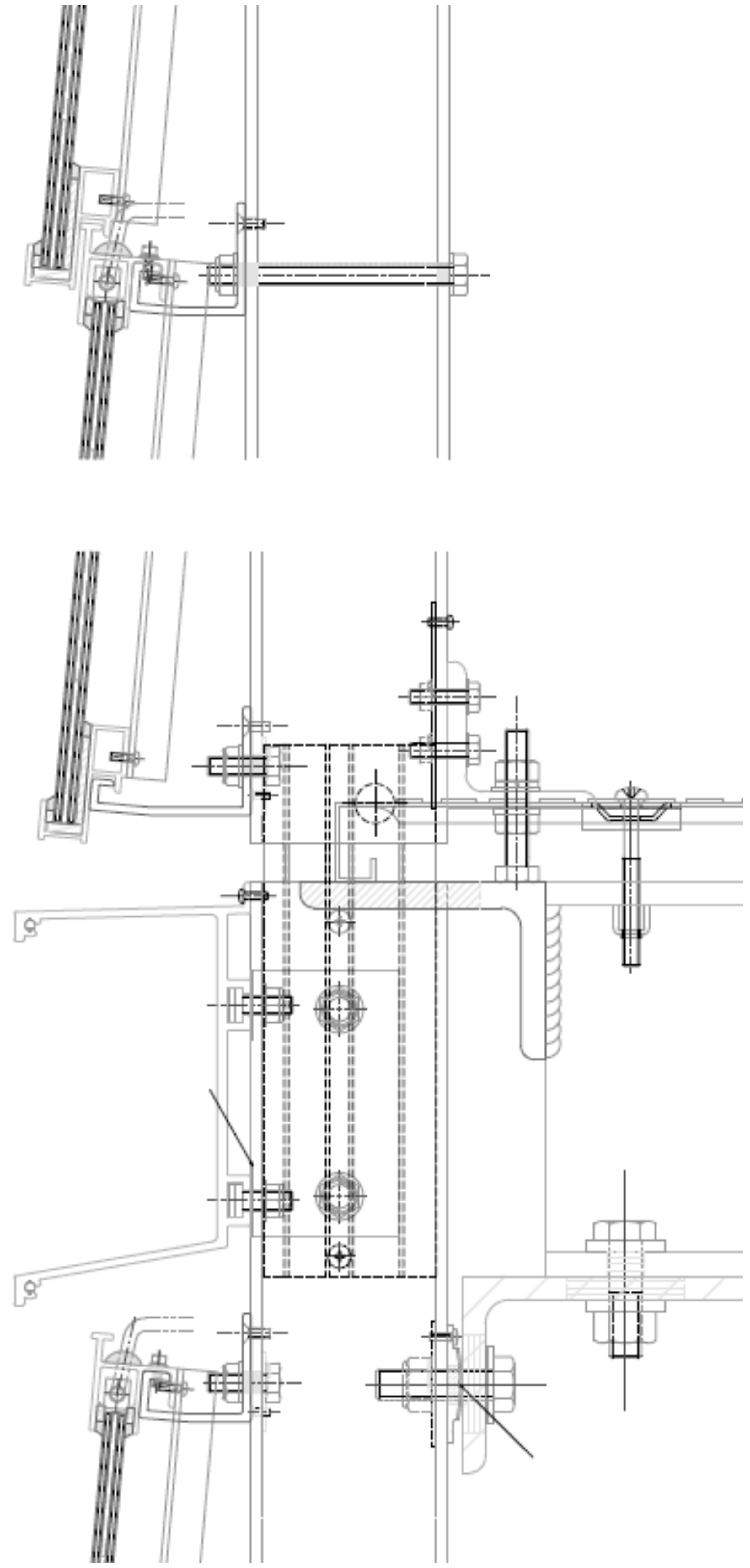
12-04. BIPV façade

Technological integration
The BIPV module for the façade of this project is a laminated module with solar cells laminated between two tempered glass panes and fixed at the top and bottom edges with an aluminum frame. According to theory, using high-transmission glass as the front cover contributes towards increasing the conversion efficiency. Electric cables are contained within the aluminum frame on the top edge to avoid visibility from the outside. Aluminum fixing clamps are adopted mainly to decrease the weight and increase weathering resistance. Each element of the façade is intended to be "maintenance-free".

BIPV Module
The project required integration of PV modules into a large wall. Efforts for cost reduction include reduction of the number of materials and components and use of standardized PV modules. Finally, the number of PV module types was reduced to only three.



12-05. Cross-section of BIPV façade.

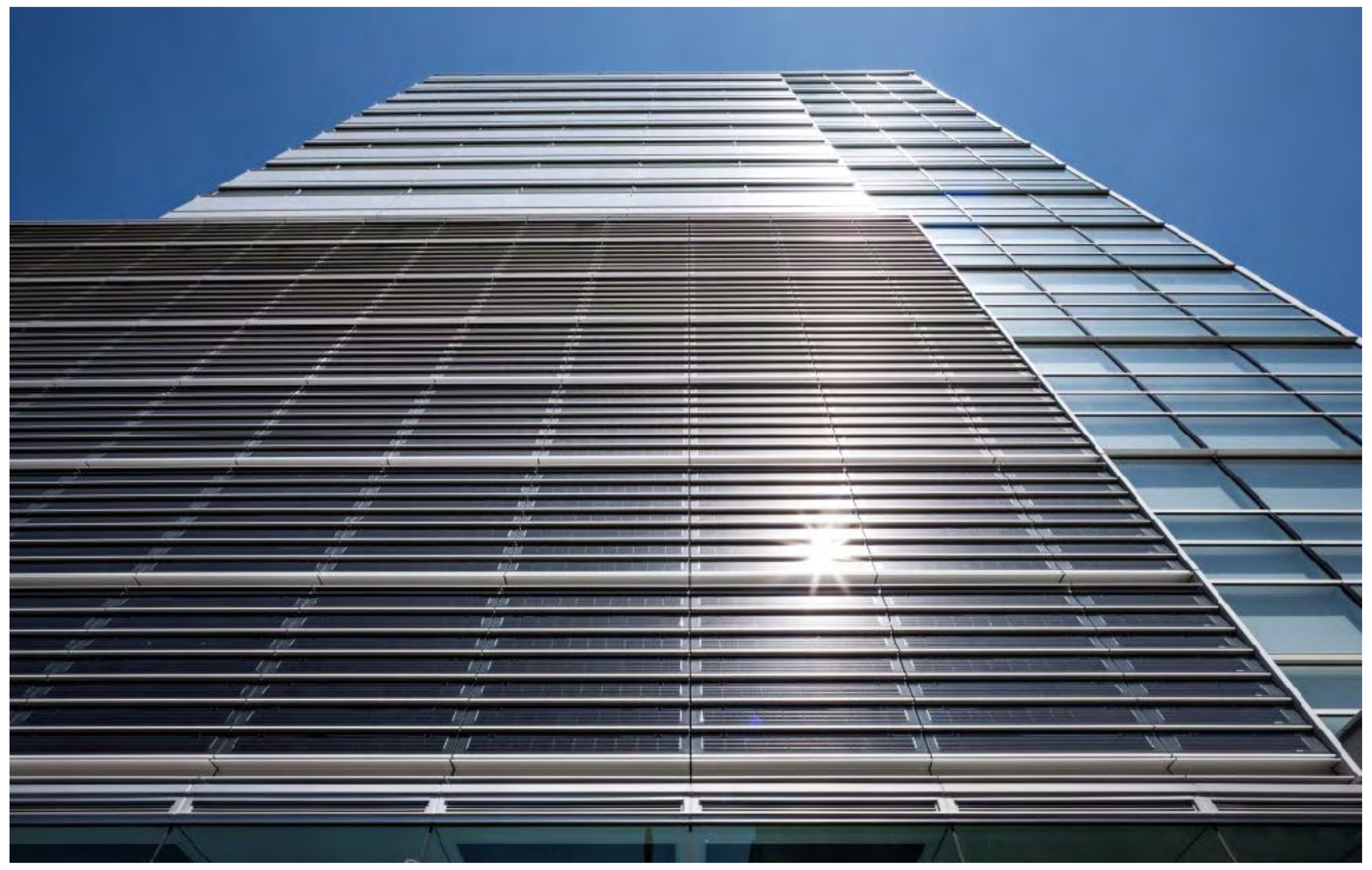


12-06. Vertical detail of BIPV façade.

Finance
The project does not qualify for the Japanese subsidy system (FIT) so all generated electricity is consumed internally. The "pay-back time" is usually recognized as a big challenge for a BIPV project, but in this project, successful environmentally-friendly architecture was more highly prioritized. To communicate this and to develop awareness of this kind of architecture within the community is the goal of the project.
Cost-reduction efforts were applied at critical points including the reduction to three types of modules.

Lessons learned
During the design of tailor-made PV modules for walls, accurate consideration of fixing or assembling of each component is required, comparing it to the design using standard modules. Then rational integration of each element, including building materials, PV cells and electric wiring, is quite significant.
The dimensions of PV modules for lower-level walls should be carefully determined because they impact strongly on the appearance of the design.
In urban areas, before PV installation on the wall, the effect of shading by nearby buildings and other objects needs to be assessed.


12-07. Outside view of BIPV façade.


12-08. Detail of BIPV façade.

Toshima Ecomusee Town, Tokyo (JA)

Project data			
Project type	New construction		
Building function	Mixed use; city hall and residential building		
Integration system	BIPV as façade cladding		
Location	2-45,Minami-Ikebukuro, Toshima-ku,Tokyo		
Architect	Kengo Kuma & Associates + Nihon Sekkei	Year	2015
BIPV system data		**Producer data**	
PV modules	Custom-made	Producer	Asahi Building-Wall Co., Ltd.
Solar technology	Mono-crystalline silicon / amorphous silicon	Address	JPR Ueno East Building, 1-3-5 Matsugaya Taito-ku, Tokyo
Nominal power	133 kWp		
System size		web	www.st-grp.co.jp
Module size			
Orientation	South, east, west and roof		
Tilt		Author/editor	Hisashi Ishii

Toshima Ecomusee Town, Tokyo (JA)

13-01. BIPV façade.

Introduction by architect Masao Kuroki, Nihon Sekkei Inc.

The project is part of a renovation programme of a Toshima city building led by Toshima ward. It is the first case of renovating a public building and achieves “no expense” for the city building construction through highly efficient utilization of the premises. In detail, the city hall functions are gathered in the lower level of the building, and residential storeys at higher levels were sold (partially provided to the former landowners). Income from the residential part was allocated for the city hall area construction. The scheme was proposed by Nihon Sekkei and subsequently adopted.
Toshima city building is located near one of the largest terminal stations “Ikebukuro”, so it is very convenient for Toshima residents and users of facilities. For the project Kengo Kuma designed the façade and his image sketch shows the building enveloped by a veil. The veil is both decorative and conveys a green city image. It is named “ECO VEIL”.

13-02. Architect Masao Kuroki.

13-02. Design sketch by Kengo Kuma

The City hall building is designed as a tree. The ECO VEIL which surrounds the building like leaves has various functions and has adopted a role as a new symbol representing Toshima ward. Panels and modules of the ECO VEIL separate the big building into a human scale and integrates the building into the town. The design of the external appearance responds to various trees along the “Green Road” between Ikebukuro station and the city building and continues the landscape of the town. “EcoMusee” provides a green city landscape with the ECO VEIL and reproduces “Toshima forest” on the roof terrace of the building. City residents can enter the roof area freely.
In the building, an open ceiling space named the “eco-void” has been created. The new city building is not only a centre for residents’ services but also forms the basis for Toshima city growth with regard to the city landscape and environment. The building functions as an environmental city hall befitting the 21st century.

The design concept existed at the first stage of the project, but during the realization process, several technology challenges arose. For the façade design, a feeling of lightness was desired, because it is intended to convey the image of a light veil. However because of restrictions due to the wind load and the variety of components, the process of connecting different elements using the same module was a major challenge. Transparency and a fine frame are required for feeling of lightness. The requirements are met by making interspaces and applying a creative support method.

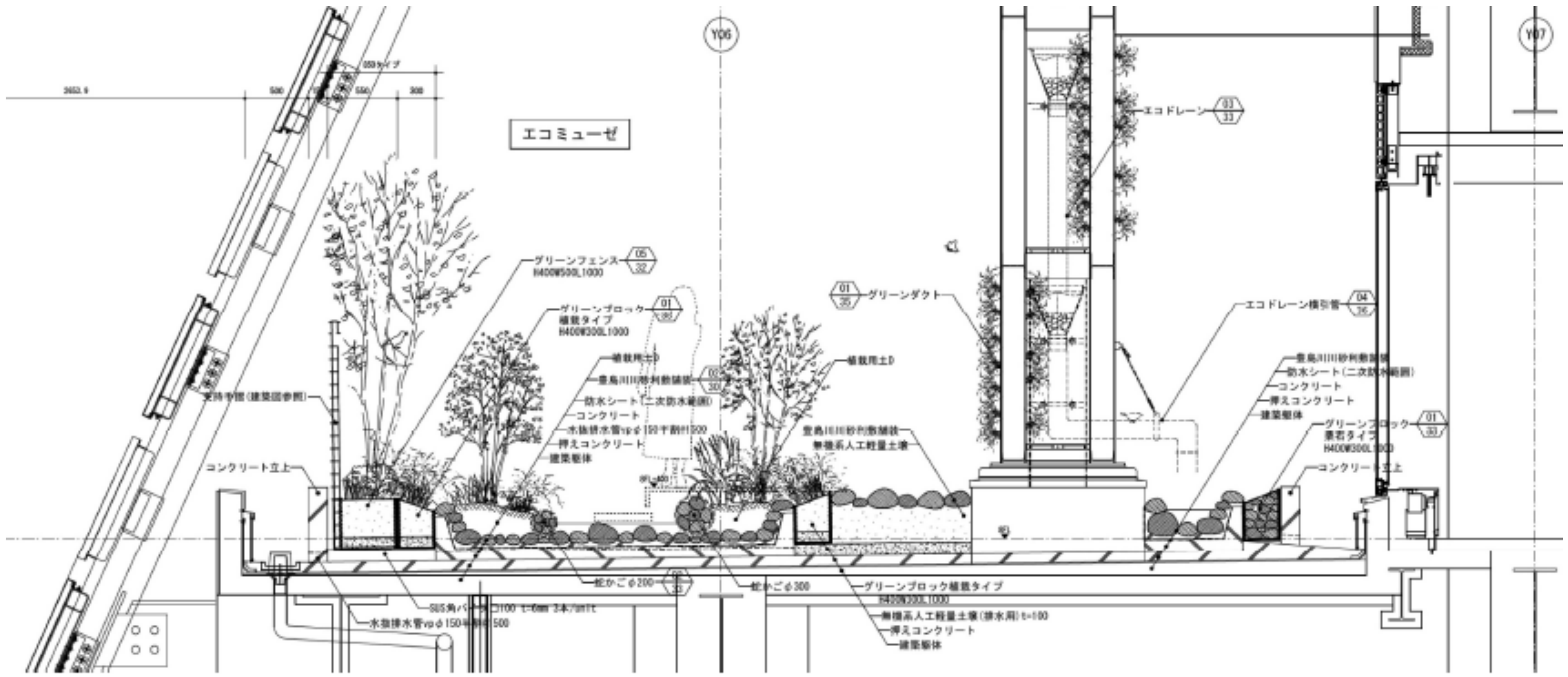
13-04. Residential façade.

Decision-making

The main reason for adopting BIPV is that the ECO VEIL, which is the main concept of the building, requires BIPV. Appreciation of one of the ECO VEIL functions, which is to publicize the environmental efforts of Toshima ward to its citizens, is another significant reason.

Process

At the design stage, experience with PV panel installation and results were gathered broadly from within the company and outside the company, before the design was finalised. During the construction stage, after close and frequent meetings with Taisei (General Contractor) and Asahi building-wall (Façade Contractor), the final design and construction method were specified.



13-05. Section of the façade.

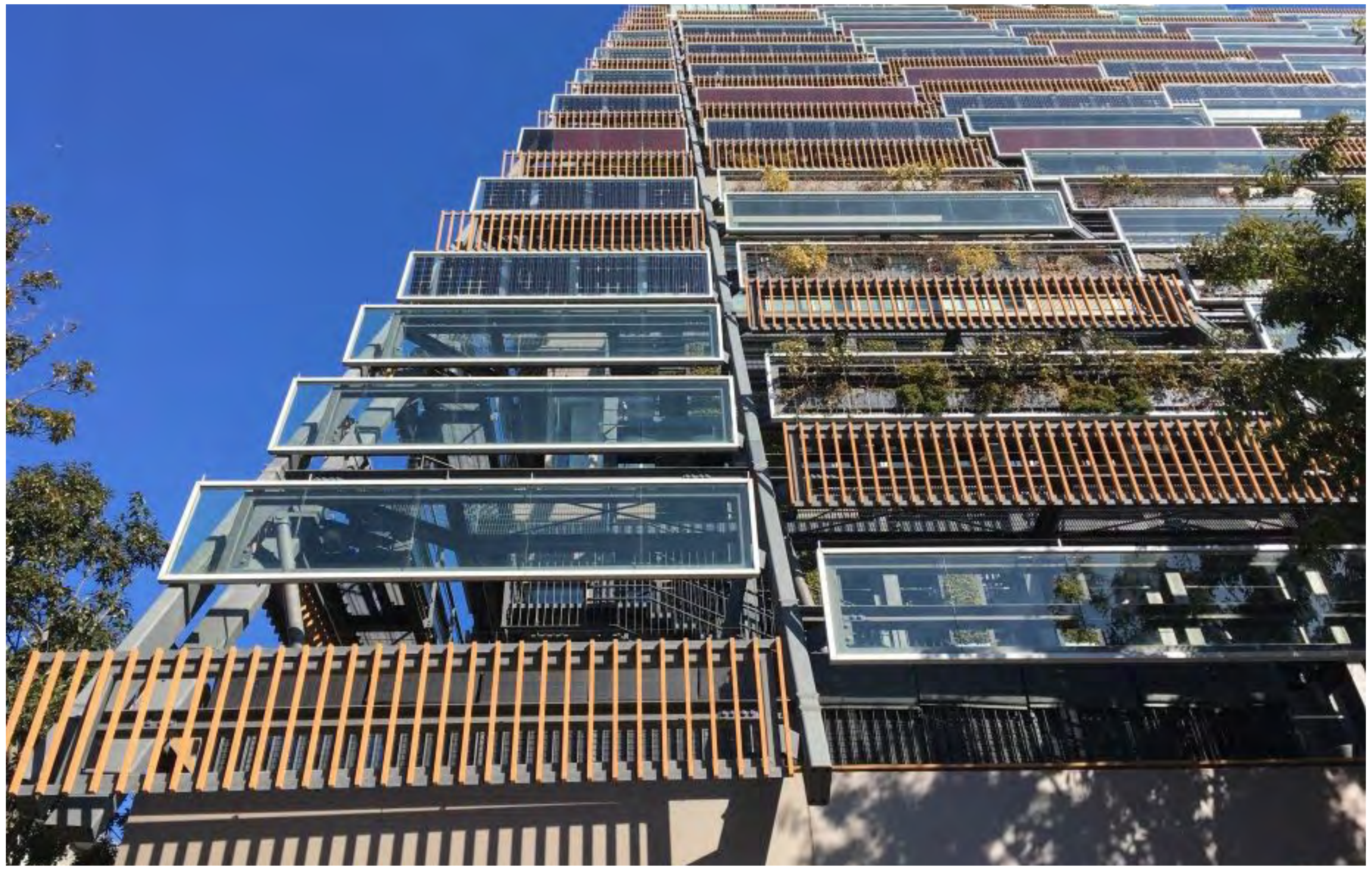
Building / system integration

Formal integration
"Toshima Ecomusee Town" combines regional government offices and high-rise high-density residential storeys. PV systems are integrated into the ECO VEIL which envelops the walls of the lower part of the building and the roof and balconies of the upper residential areas. The "Eco Veil" adopts two type of modules, mono-crystalline silicon and amorphous silicon, for appealing diversity and excellent design. Monocrystalline silicon PV is installed on the roof and amorphous PV is installed as balcony balustrades.

Energy integration
"Environmental city hall leading environmental measure" is symbol for Toshima ward's goal of "development of an environmental city". The building creates green-rich space for inhabitants and actively adopts environmental technology including photovoltaics, natural lighting, eco-lighting, water circulation system using rainwater harvesting, and a district heating and cooling system. As a result of these environmental efforts, the CO_2 emission of the city hall area is reduced by more than 30% compared to the former city hall. The total amount of installed PV power from the entire ECO VEIL is 57kWp and is sold through the FIT feed-in-tariff programme. The total installed PV power on the roof and balcony of the upper residential area is 77kWp and is consumed in the residential common area.

Technological integration
A light transmitting type of PV module (amorphous silicon) is used for the balcony balustrades of the high-rise residential building. It has the function of electricity generation without disturbing the view from the balcony. It is the largest PV system on balconies in a high-density residential building in Japan.
ECO VEIL is a façade which has various functions like the tree leaves of a tree. Several panels of the same shape with different functions, including mono-crystalline silicon PV modules, amorphous PV modules, glass panes, wall greening and wooden louvres are integrated into the façade.

13-06. BIPV façade.


13-07. A variety of elements in the façade.

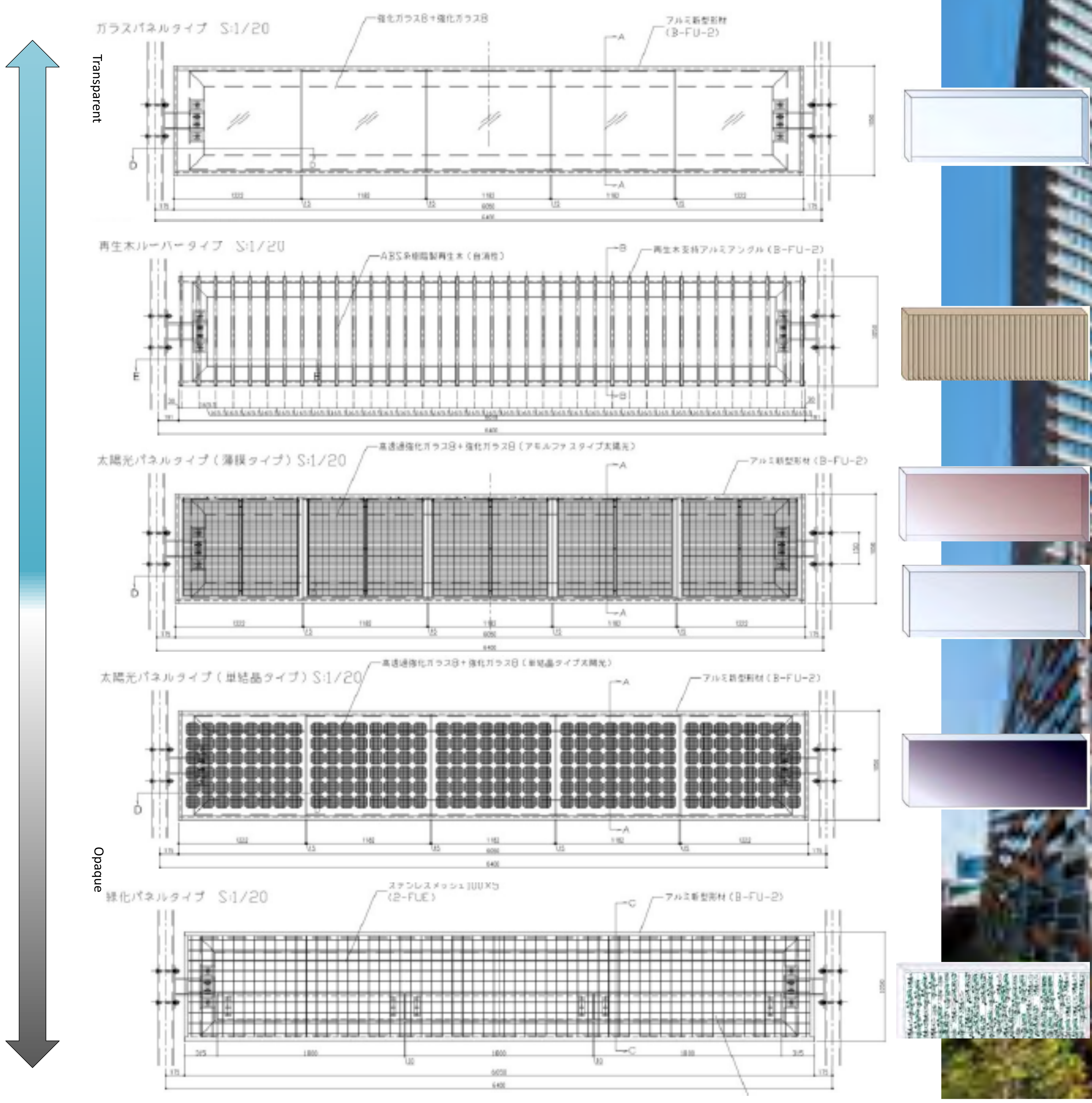

13-08. Detail of different elements in the façade.


13-09. Inside view of the BIPV balustrades.


13-10. Visit by IEA-PVPS Task 15 to the building.

Finance
Electricity generated by the ECO VEIL at the lower is sold within the FIT programme and electricity generated on the roof and balconies at the higher levels is consumed on site in the residential common area.
One of the challenges of BIPV is the pay-back time, but the motivation of the project is not the pay-back time but success of the ECO VEIL concept and public information about the city hall effort to inhabitants.
A cost reduction evaluation was executed for critical areas and due to the cost estimation, the number of BIPV modules was reduced, but finally the project completed, keeping the original concept.

Lessons learned
In this project, BIPV is a component of the ECO VEIL. More design conditions should have been clear. Under the given circumstances, the challenges of installing BIPV were hard to solve.
BIPV which is installed close to visitors access to the roof garden, is efficient for advertising the environmental effort and also makes careful installation necessary in detail.



13-11. Module typology.

13-12.

Singyes Solar Office, Zhuhai (CN)

Project data			
Project type	New Construction		
Building function	Commercial Building		
Integration system	Curtain wall, canopy, shading, louvre parapet		
Location	Zhuhai, Guangdong		
Architect	Mr. Adam Huang		
BIPV system data		**Producer data**	
PV modules	Custom-made systems (4)	Producer	Singles Solar
Solar technology	Monocrystalline silicon	Address	Zhuhai, Guangdong (China)
Nominal power	235 kWp	web	www.singyessolar.com
System size			
Module size			
Orientation			
Tilt		Author/editor	Limin Liu, Wei Zhu

Singyes Solar Office, Zhuhai (CN)

14-01. BIPV façade and PV roofs.

Interview with Mr Liu (Singyes Solar) and Mrs Luo (chief architect).

Mr Liu: The core technologies of our group are photovoltaics and curtain walls, so as the business owner, we naturally apply these technologies to our buildings. Currently, the incremental cost of BIPV is very high, but from the analysis of the entire life cycle of the building, the payback period in BIPV system construction is very short.
Mrs Luo: In order to reach the goal of an ultra-low-energy, green building in the climate zone with hot summers and warm winters, we decided to adopt the BIPV technology to increase the self-sufficiency in energy sources. However, there are many challenges to reach the target especially concerningin the building height.
Mr Liu: As for BIPV, it can not only generate electricity to reduce the energy consumption during the operation of the building, but also extend our group's brand.
Mrs Luo: On the one hand, the structural stability and safety of the curtain wall should be considered, which means that the PV modules must be able to withstand moderate wind pressure and deformation.
Mr Liu: Singyes Solar is a high-tech enterprise committed to energy conservation, environmental protection, renewable energy and new materials. We are working hard to transform every building into a miniature power plant, which is part of our enterprise culture. At the meantime, it's our duty to spread the green concept of energy saving.
Mrs Luo: In addition, the multifunctionality of the curtain wall was taken into account, which refers to energy generation, ventilation and cooling of the PV modules in the design. When we turn off the ventilator in summer, the hot air generated by the PV modules can be easily exhausted to the outdoor space by the chimney effect. On the contrary, the hot air in the summer would come inside if the devices were turned on. All of the above behaviour can increase the yield of the PV modules and reduce the building energy consumption at the same time.

14-02. Mrs. Luo, chief architect.

Decision-making

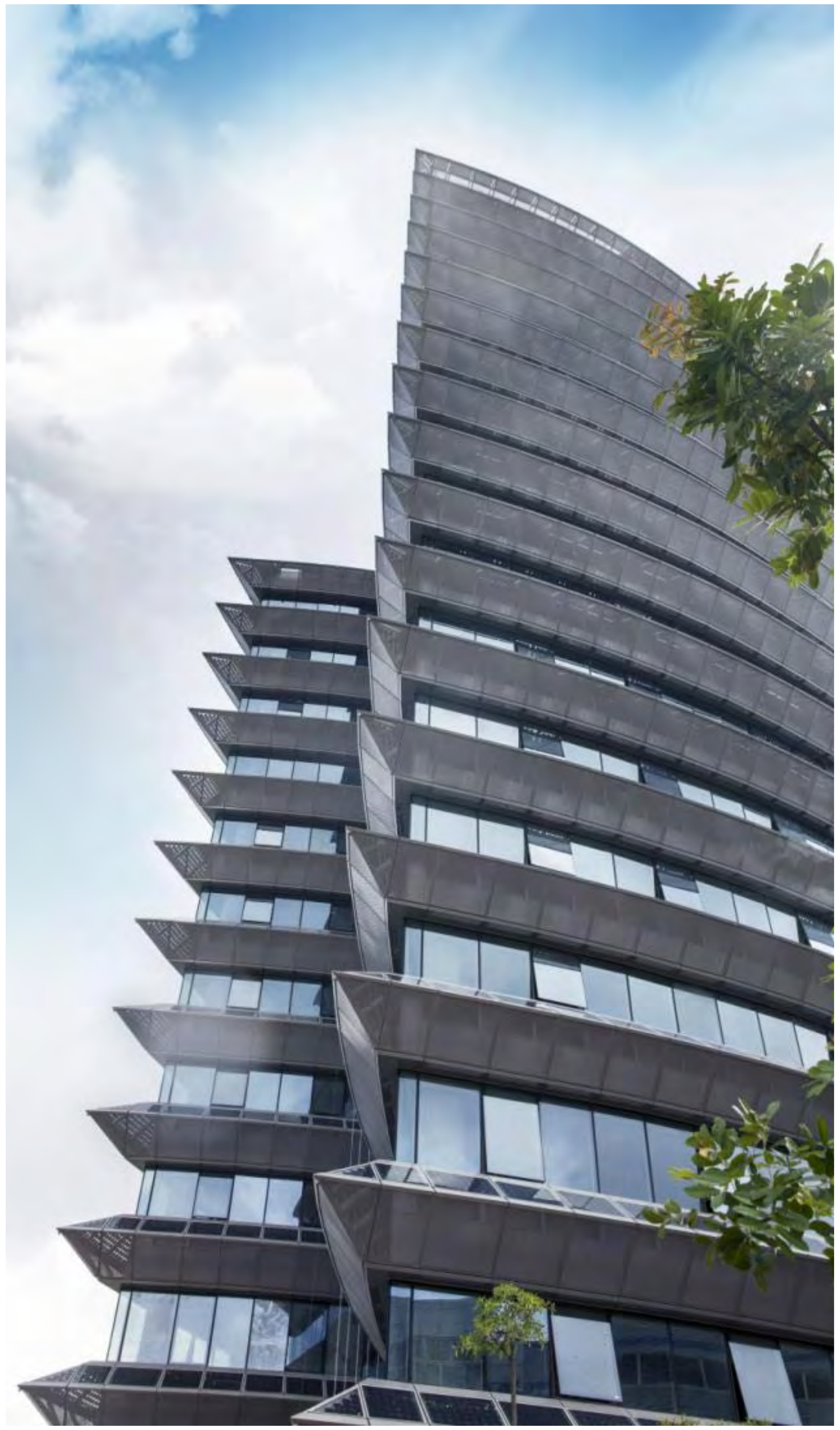
For the decision making of BIPV, three aspects have been taken into consideration. First of all, to achieve our target of ultra-low-energy consumption, PV should be used in this project without any doubt. Second, the BIPV-system can make the building components to become multifunctional. Thus, PV can not only generate power, but also support shading and ventilation, which can make a great contribution to energy-savings for this project.

Finally, a BIPV-system is perfect win-win solution, we can increase the PV power generation efficiency and optimize the building performance through a balanced design.

Process

From December 2012 to March 2014, 'GREEN YES' completed everything from the planning to the design stage and obtained a construction permit. In May 2017, 'GREEN YES' was completed and put into use. After completing construction, the PV power station was connected to the grid. Leading the PV industry, Singyes Solar is a reliable integrated supplier of PV modules and a design and installation provider for PV systems.

14-03. PV roof for shading the roof garden.



14-04. Façade of the building.

Building / system integration

Formal integration

This project has four PV systems, including a multifunctional PV curtain wall, a double-skin roof, a PV louver parapet, a double-skin PV canopy and other configurations form. In addition, we utilize the micro-grid and local DC micro-grids to power the building's data centre creatively.

Energy integration

These four PV systems generate about 150,000 kWh power per year for this office building with a building area of 23,546 m^2, accounting for 12.7% of the total energy consumption of the building. The annual generating capacity of the PV roof shading, the PV curtain wall, the PV carport and the PV louvre parapet respectively is 77,287 kWh, 56,003 kWh, 14,501 kWh and 2,520 kWh power, contributing to 51%, 37%, 10% and 2% of the total generating capacity of the PV systems. Furthermore, the average daily thermal yield from two other PVT systems is about 10,832 kJ and 13,253kJ, which can provide about 60,000 litres of hot water for the building each year.

Technological integration

Multi-functional PV curtain wall (130 kWp). The multi-functional PV curtain wall combines the two functions photovoltaic power generation and natural ventilation in one element. A 180° rotatable ventilator is installed on the façade. The system opens the outer channel in summer. The hot air is exhausted by the wind pressure and thermal pressure to increase the power generation efficiency of the photovoltaic modules. In winter, the inner channel is opened to bring warm air in, which can improve the interior comfort. When it comes to the transitional seasons, the function can be freely adjusted according to the indoor and outdoor temperature, humidity, air quality and other conditions.

Landscape-style PV roof shading (78.8 kWp). The double-roof design consists of a roof garden and a shading solar power plant that can greatly improve the comfort and functionality of the rest area on the roof. The photovoltaic modules are in the form of an overhead roof, which develops a sun-shaded place to walk on. A large number of green plants grow beneath the photovoltaic modules within a roof garden.

Double-skin PV canopy (17.5 kWp). The double-skin PV canopy achieves both the role of rain protection and sun-shading. The spacing design of the photovoltaic modules ensures that the lighting effect at the entrance is not affected.

PV louvre parapet (8.5 kWp). The use of laminated glass photovoltaic modules can provide shade to the rest area, reduce the roof wind speed, and improve the comfort of the rest area.

Photovoltaic thermal system. Photovoltaic modules are installed on the external protective structures, awnings, and roofs, together with photo-thermal components, so that the building has both the function of power generation and a hot water-supply.

Ceramic glazing to achieve PV module appearance. Resources would be wasted if all external façades used PV modules because of the lack of solar radiation in some façades. neither economic nor reasonable. To solve this problem, our R&D team has developed a product named ceramic glazing to imitate the PV module appearance. This is widely used on the northern façade of this building, where the radiation is not sufficient, and some specially-shaped or long-shadowed locations to ensure the overall consistency and aesthetics of the building. This measure significantly reduced the investment cost of the PV system.

Plug-in type transparent single-glass photovoltaic modules. PV modules in the multi-functional PV curtain wall system are installed with a plug-in frame type, which can be directly mounted on the corresponding keel to achieve the purpose of rapid installation. At the same time, replacement and maintenance cycles can be shortened without affecting power generation.

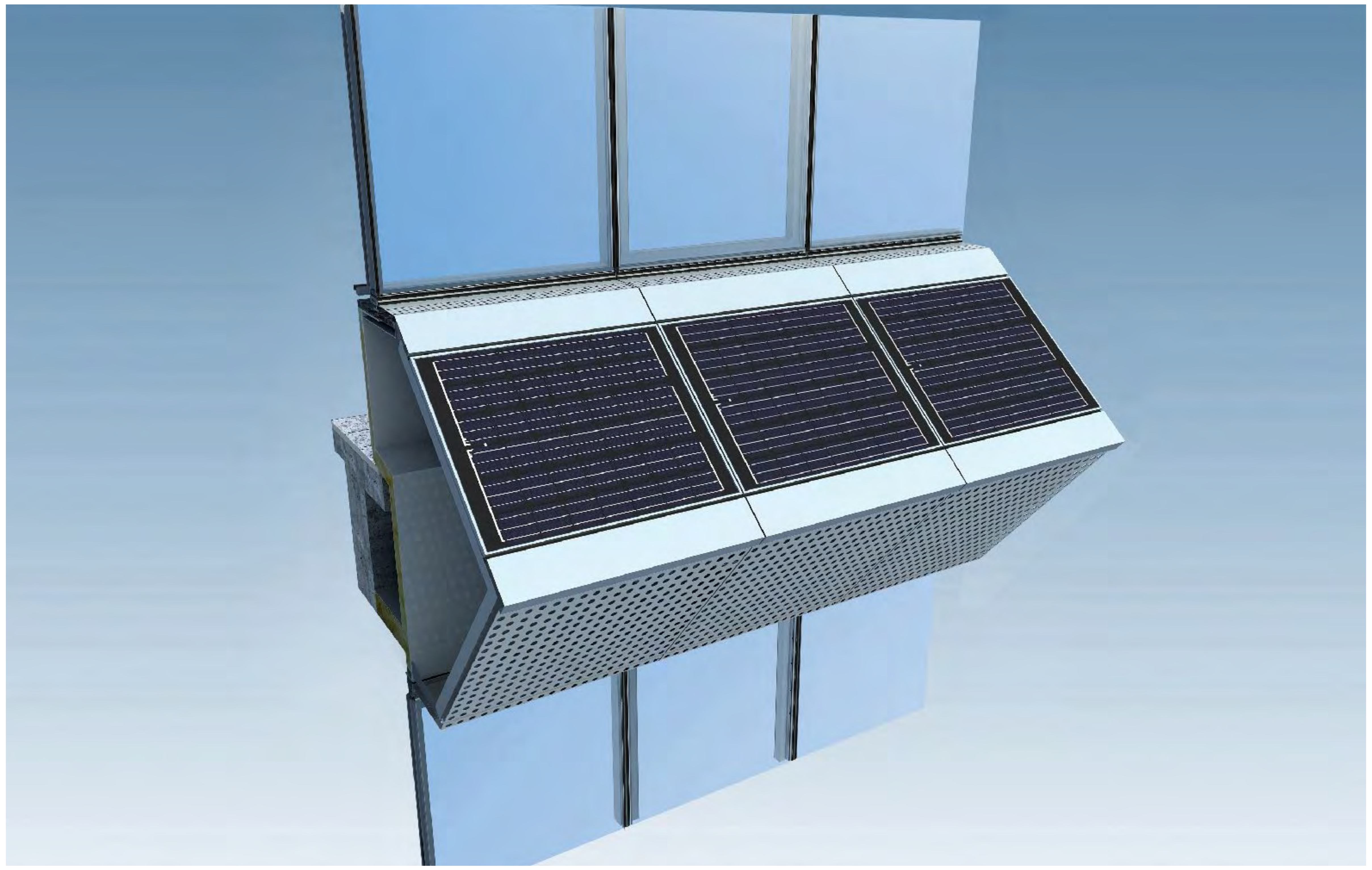
Smart micro-grid. In this project, the micro-grid uses two sets of energy storage inverters to run in parallel to form an AC dual-ended hybrid micro-grid redundant system. The energy management system can effectively regulate and control power resources by energy storage, and can well balance the difference in electricity consumption between day and night as well as different seasons by adjustment to ensure grid security, realizing the traditional UPS function to protect the load side power.

14-05. Southwest view of the building.


14-06. Roof structure from the inside.


14-07. BIPV canopy.


14-08. Aerial view of the main building.


14-09. Artist's impression of the BIPV parapet elements.

Installer Miss Mao:
The installation of PV systems on the façades was the most difficult part of the project. On the one hand, the shape of the building is a curved profile, which means that the installation method cannot be followed step by step, and every irregularity and the inclination of the PV modules should be taken into account. On the other hand, when it comes to the wiring of the PV system, the cables must be concealed in the curtain wall and then be led to the interior to be combined within the group of PV modules in the string design. The high-altitude location increased the difficulty of installing the façade of the PV system. Through communication and discussion with the architects, a façade design scheme that met the aesthetic criteria was found and an efficient solar energy system was created.

Architect Mr Huang:
The original architectural design scheme was not retained. After optimization of the buildings, the façade area of solar energy utilization increased by 18.34% compared to the previous scheme, effectively increasing the installation area of PV power generation systems and solar hot water systems. As an architect, perhaps what I considered was tend to ensure that the artistry of the building was not affected by the addition of PV systems. We pursued the goal of beauty while still meeting the functional needs. Sometimes it is very hard to have it both ways but Singyes did it. ‘GREEN YES’ is a very successful and typical case. The structural safety and electrical safety of PV building are all very well designed.


14-10. Mrs. Mao, installer


14-11. BIPV façade.

Finance
We can estimate the annual power generation from the total installed capacity (235,097 kWp) of the PV system. The peak electricity price for self-consumption is 1.322 RMB/kWh. The regular electricity price for self-consumption is 0.8012 RMB/kWh. The subsidy is 0.42 RMB/kWh. The average incremental price of the PV system is about 10.5 RMB/W. According to the calculation, the investment recovery period of the entire PV system is about 11.3 years.

Lessons learned
'GREEN YES' is an excellent BIPV project involving the top experts and researchers' resources in the field of building energy conservation in China and the USA. Based on the principles of "passive priority and active optimization", the team has designed four PV systems, applied the PV micro-grid system to this building creatively and created a green data centre for clean power. Although we took two years to do research for the application of BIPV in this building, there are two ongoing topics that may have another lessons for us. One thing are the challenges, we faced when we want to control the ventilation in the open offices. The people have different feelings about comfort. The other lesson is, in order to reduce the cost and for the convenience of manufacturing, the BIPV modules have transparent plastic backing, which has not been verified in real circumstances before and this may bring some uncertainty of durability for the BIPV modules.

In December 2016, the China High-tech Industrialization Research Association confirmed the'GREEN YES' to embody the identity of scientific and technological achievements. This installation has reached an advanced international level in curtain wall integrated controllable ventilation integrated into curtain walls, sunshading and power generation technology field. 'GREEN YES' achieved China's three-star green building design certificate and the US LEED BD+C NC platinum certification. In addition, it also received the International Eco Design Award, the 2016 First National Distributed Photovoltaic Application Innovation Gold Award, and the SBDE 2015 Challenge Cup Solar Construction Competition Design Award. Singyes Solar is committed to building the most representative green building and ultra-low energy building in the same climatic region in South China and even in the world.

14-12. Artist's impression of the main building.

Solsmaragden Office, Drammen (NO)

Project data			
Project type	New construction		
Building function	Office building		
Integration system	Glass façade		
Location	Grønland 67, 3045 Drammen (near Oslo)		
Architect	Ingebjørg Lien, LOF Arkitekter, Oslo	Year	2015
BIPV system data		**Producer data**	
PV modules	Issol CENIT 220-6112, 55-170 Wp	Producer	ISSOL, Strøm Gundersen (mounting system)
Solar technology	Monocrystalline silicon, green printed glass	Address	ISSOL sa, Rue du Progrés, 18-4821 Dison (B)
Nominal power	115.2 kW_p	web	issol.eu
System size	1011 modules, 1242 m^2		
Module size	26 different shapes, from 590 x (960 to 2790) mm^2		
Orientation	Modules: 205 east, 372 south, 423 west,		
Tilt	90° (vertical)	Author/editor	Anne Gerd Imenes

Solsmaragden Office, Drammen (NO)

15-01. BIPV façade at Solsmaragden.

15-02. Adapted BIPV module sizes.

Interview with Mr Trond Aasheim, CEO and owner of the building development company Union Eiendomsutvikling, and Mr Paal Skjaeggestad, CEO of the electricity utility company Glitre Energi, the largest tenant in the building.

Mr Aasheim: The local energy company Glitre Energi needed new premises and announced a competition. We wanted to do something special to contribute to the green transformation, and to create an attractive building for environmentally conscious tenants. We prepared an offer where the whole façade would consist of solar modules. The energy company liked the idea and we won the competition.

Mr Skjaeggestad: We want to thank Union Eiendomsutvikling for the great building you have made for us. On the behalf of all employees I have to say we are very satisfied. The premises are modern, light and efficient. The green profile of this building is ideal for an energy company. We want to be part of the solution to reduce the global CO_2 emissions.

Mr Aasheim: This has become the most magnificent office building in Drammen. It is possibly also the smoothest building process we have ever experienced, thanks to a great collaboration with the contractor and excellent advisors. We went through a three-step process: First we introduced efficiency measures beyond the current building standard requirements. Next, we addressed additional measures to achieve the passive-house standard. Finally, we added solar modules to the building.

Mr Aasheim: This is really locally produced energy. The electricity we use to light up all rooms inside the building has been generated by the envelope of the building. With solar power from both the PV façade and a rooftop system, the Solar Emerald produces close to one-fourth of the building's total energy needs, which makes us very proud.

15-03. Mr Paal Skjaeggestad (CEO, Glitre Energi), Mr Tord Lien (Norwegian Minister of Petroleum and Energy), and Mr Trond Aasheim (CEO, Union Eiendomsutvikling) at the official opening of Solsmaragden.

15-04. BIPV wall edge adaptations.

Decision-making
The initiative to apply a PV system to the building was taken by Mr Trond Aasheim, CEO of the owner company Union Eiendomsutvikling. It was in the company's interest to build an innovative building with an environmental image to attract tenants. The idea of including a PV system was initiated at an early planning stage, and the final decision was made during the construction phase. The architect wanted an aesthetic façade, and in discussions with the PV supplier company, FUSen, the decision was made to install a BIPV system on the façade.

Process
The design and construction process was organised as a collaboration between the enterprise and contractors. As the original offer from Issol for mounting the PV façade was too expensive, the owner coordinated the development of a new method using standard glass façade mounting adapted by the entrepreneur and using a local electrical installer company. The module design and the mounting method was developed as a collaboration between the building owner (Union Eiendomsutvikling), the project architect (LOF Arkitekter), the entrepreneur (Strøm Gundersen), the electrical installer (Powertech) and the PV supplier companies (FUSen and Issol). The final PV system quality control was performed by FUSen.

Building / system integration

Formal integration
The PV system is integrated into the façade of a seven-floor office building, which is located in the pier area of Drammen city. A river flows to the Northeast and commercial building blocks of similar height are located in the nearby surroundings. The building realizes outstanding environmentally friendly architecture by replicating a green wall according to requirements of the architects. All formats were adapted to the façade to give a holistic architectural impression. The formal integration influences the output of the PV system to some degree. The choice of coloured modules reduces efficiency by around 17% compared to traditional modules, and the different façade orientations are not all ideal for maximum electricity generation.

Energy integration
The building satisfies the Norwegian passive-house standard NS3701 and is classified as a low-energy building with energy label A. Normally, all of the generated PV power is self-consumed. The BIPV façade system has a generation profile that fits well with the consumption profile of the building. As the building also contains a traditional rooftop BAPV system, the total generation at certain times in summer may require export to the grid. The total electricity generation is estimated to contribute 23% of the total building electrical consumption, with the BIPV façade contributing around 56 MWh of the total estimated 106 MWh annual production. Some shading from the surroundings may affect the façade system output.

Technological integration
The modules are of the type Issol CENIT, customized in terms of size and colour. The frameless glass-glass modules use standard mono-crystalline silicon solar cells, with 4 mm building-approved safety glass at the front and back side. The green pattern is printed on the inside of the front glass. The modules are mounted as the outer cladding material of the building, ventilated by natural outdoor air. The mounting structure was especially developed for the project by the system installer and produced in Norway. Standard brackets for façade glass mounting are used to fasten the modules to the wood battens of the climate wall. Wall reinforcement of the building structure was required due to the extra weight of the façade. Cabling is pulled through the façade and hidden in the ceiling, with inverters of the type SMA Sunny Tripower (3-20 kW according to the different string sizes) located on different floors.

15-05. Detail of the green screen-printed module.

15-06. Mounting of the BIPV façade modules.

15-07. Architectural details from completed BIPV façade.

15-08. Mounting BIPV modules on a curved section.

15-09. Alternative patterns for printed BIPV modules.

Interview with PV advisor: Thor Christian Tuv, CEO at FUSen

For the Solar Emerald we started a separate R&D project for green solar cells. This is very unusual; in an ordinary building project everything is streamlined to ensure that the process is as fast and cost-efficient as possible. The efforts made by Union Eiendomsutvikling should inspire other building developers to do the same. A traditional procurement model would not have worked in this project. The product was not available on the market when we started, it was commercialized underway. By breaking out of the traditional way of doing things, it is possible to create new solutions. This is a great example of how to achieve locally generated electricity and an environmentally correct building. It is something that everyone should do!

Interview with public financer: Ole Aksel Sivertsen, marketing manager of commercial buildings at Enova

Enova chose to finance this project because the solar cells are used as an integrated part of the façade. It is a very exciting and innovative solution, which contributes to the increased use of PV technology in Norway. The costs are still difficult to defend on a short-term basis, but we believe the technology has a market potential on the longer term.

15-10. CEO and founder of FUSen, Thor Christian Tuv.

15-11. BIPV and glass façade.

15-12. Union Eiendomsutvikling.

Finance

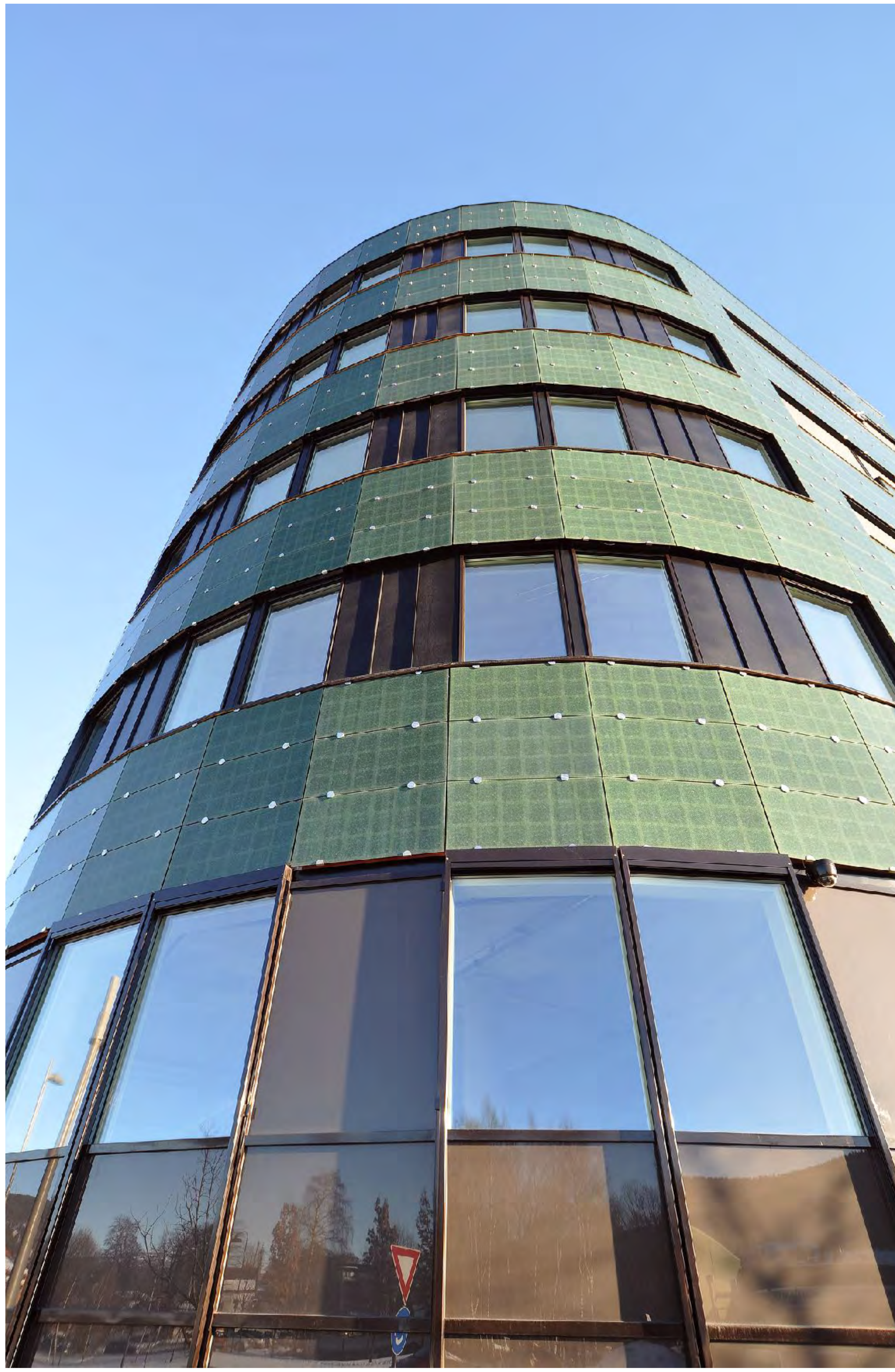
The size of the PV installation was not influenced by the financial analysis, as aesthetics was the main criterion. It was decided that the green-coloured BIPV modules should cover the full façade, despite not all areas being of ideal orientation for power production, to create the right appearance. Costs were increased due to the customized modules of different sizes and the complex string design.

The added cost of the BIPV façade was 382 k€ (308 €/m^2), where costs associated with a typical façade material have been subtracted. The added cost represents 1.4% of the total building cost. With the public funding received for the BIPV façade, the total added cost was 213 k€ (172 €/m^2). The owner calculates 3-4% return on the additional investment compared to a traditional façade. A lifetime of 25-30 years and low maintenance costs are foreseen.

Lessons learned

Overall, nothing went wrong in the project and the building owner is pleased with the construction and implementation of the PV system. A BIPV façade is still costly, especially for customized products. At the time of planning and design, not many suppliers were available. The coloured PV technology was not well developed and the project team travelled around Europe to find a suitable solution. The mounting solutions offered were expensive and not suited for Norwegian building methods, which required the use of safety glass in façades. Hence, our own methods were developed.

The smooth collaboration between the project actors was imperative to develop new technology that satisfied the requirements for cost, appearance and installation method. Using the competence of local companies was a key factor. Despite some challenges with shading, a low energy price for selling surplus power to the grid, and a lack of knowledge about new products, the building owners state that they would do it again – even without public financial support.



15-13. Curved section of BIPV façade.

Väla Gård office, Helsingborg (SE)

Project data			
Project type	New construction		
Building function	Office		
Integration system	Roof		
Location	Kanongatan 100, Helsingborg		
Architect	Tengbom arkitekter	Year	2012
BIPV system data		**Producer data**	
PV modules	NAPS Saana	Producer	NAPS Solar Systems Oy
Solar technology	Monocrystalline silicon	Address	Rosasgränden 4, 00390 Helsinki
Nominal power	70 kW_p	web	www.napssolar.com
System size	450 m^2		
Module size	-		
Orientation	Southwest		
Tilt	45°	Author/editor	Rickard Nygren

Väla Gård office, Helsingborg (SE)

16-01. BIPV roofs in south Sweden.

16-02. Architect Patrik Ekenhill (Tengbom arkitekter).

Interview with architect Patrik Ekenhill (Tengbom arkitekter), and project manager Daniel Ryman (Skanska).

Aesthetics
Corresponding to the neighbouring old stone barn, the new office building presents two imposing gables to its visitors, and pitched roofs which were specified by the detailed development plan. The large roofs provide space not only for a third floor but also for solar energy harvesting. Whereas part of the roof is covered with traditional wooden boards, the south facing slopes are fully covered by dark monocrystalline standard-size frameless panels parallel to the pitch. The solar panel glass is slightly textured, giving a varied surface and a vivid expression, harmonizing with the surrounding dark wooden surfaces.

Challenges
Initially the dark solar panels were considered to be a constraint, which would be better off on a bright building. Only a very few custom-sized panels were needed to make them fit. Rainwater gutters were suggested to be fully integrated into the eaves. The reason they did not in the end was related more about to general concerns regarding moisture management than due to the solar panels. When the building was put into use, one out of five inverters failed, leading to an installation of a lightning alarm to avoid future production losses.

Decision-making and process

The aim from start was to achieve a net zero energy building, fulfilling the standards of Skanska's own ambitious goals of a 'Deep green' office building. Thus the use of solar energy was prescribed already in the architectural competition, with the level of integration taken into account but not as a prerequisite. Use of solar panels was not regulated in the detailed development plan. A decision to extend the solar roof was made by Skanska during the design process. Solar panels and the mounting system were delivered by NAPS Solar Systems.

16-03. South façade and BIPV roof.

16-04 BIPV roofs for a zero-energy office.

Building / system integration

Formal integration

Väla Gård is situated at the northern entrance to Helsingborg, in south Sweden. Alongside a listed granite barn is the new office building, with characteristic gables and pitched solar roofs and.

Energy integration

The PV roof produces about 68 000 kWh annually. The summer surplus is exported to the grid, to be bought back during winter. Solar power covers the buildings energy use of 65 000 kWh/year for heating by a ground heat pump, hot water, and ventilation (to achieve this 26 000 kWh electricity/year is required). The tenants' use of electricity exceeds 44 000 kWh/year.

Technological integration

Tilted to the north wooden board roofs follow the lines of the wooden panel façade cladding, while solar panels cover the sunny sides with neither visible frames nor profiles. Wooden boards as well as solar panels are mounted on top of a rainwater proof bitumen membrane.

16-05. Vegetation on the roof is avoided.

16-06. View from the public street.

16-07. Adaptation to the historical environment.

Energy specialist

Skanska's in-house energy expert Björn Berggren was a key person in the process. In order to make it possible for the solar power yield to exceed total electricity use, every kWh in the calculation had to be scrutinized. Apart from designing an effective heating and ventilation system, within the airtight and well insulated building envelope, a lot of effort was made to include users' behaviour in the energy calculations. One of the major electricity loads to be discovered was the refrigerated food-vending machine, that used as much as 10% of the total solar roof yield (6700 kWh/year).

16-08. BIPV roofs for a zero-energy office.

16-09. PV modules aligned with ridge and roof edge.

Finance

The overall goal for the project was to achieve a building that annually generated more electricity than it consumed (tenants' electricity consumption excluded). The initial plan was later changed and the solar installation was extended by more than 50%, almost covering both building related electricity consumption as well as tenants' electricity consumption. Since the total project budget would permit the extra solar panels, the option of covering the rest of the roof with wooden boards instead was not really an alternative. The price for producing 1 kWh was not the main driving force but instead the goal to minimize the need for externally bought electricity.
The governmental financial grant for solar power was not taken into account in the project budget, so this was perceived as a welcome bonus of 45% of the total cost of €300 000.

The local energy company and grid owner Öresundskraft is buying exported solar electricity for the average instantaneous price on the Swedish market. Additional income from electricity certificates has not been taken into account in the calculation, since they are considered to be small and unpredictable. The solar installation is calculated to be paid back in 12 years.
The major value is said to be that the office building achieves a 'Plus energy' brand, a LEED-Platinum certification, and Skanska's own 'Deep green' label. The visibility of the solar installation is also regarded to be a major value. All services are included in tenants' rental agreement, so no cost or risk due to the solar installation is added.

Lessons learned

The project management notes that the question of payback time is never raised for any other part of the building envelope or structure, only for the integrated solar cells. A battery as a night storage unit could have increased the direct consumption of solar generated electricity corresponding to half of the electricity for building use.

Since erecting Väla Gård, investments in integrated solar power have not accelerated substantially. More common environmental certifications such as the national 'Miljöbyggnad' are dominating. Also other issues such as rain water treatment subjects solar power generation to competition against green roofs.

16-10. Modern roof material next to traditional.

Solar Silo, Basel (CH)

Project data			
Project type	Refurbishment		
Building function	Office building		
Integration system	Ventilated opaque façade / pitched roof		
Location	Dornacherstrasse 192, 4053 Basel		
Architect	Baubüro in situ AG	Year	2015
BIPV system data		**Producer data**	
PV modules	Kromatix™ modules	Producer	Emirates Insolaire L.L.C
Solar technology	Monocrystalline silicone	Address	Al Quoz Ind. area #4, Street #10, Dubai, UAE
Nominal power	24 kWp	web	emirates-insolaire.com/en/Products
System size	159 m^2		
Module size	2 special formats (façade), 1588 x 806 x 13 mm (roof)		
Orientation	North (façade), south (façade and roof)		
Tilt	11° (roof), 90° (façades)	Author/editor	Pierluigi Bonomo

Solar Silo, Basel (CH)

17-01. BIPV façade.

17-02. Ms. Kerstin Müller (l) and Ms. Barbara Buser (r).

“We thought «If we do something, we do something special» and then the decision was made to use BIPV on the façades”

Interview with the architect Kerstin Müller (Baubüro in situ AG) and Thierry Bosshart (iRIX Software Engineering AG and member of board).

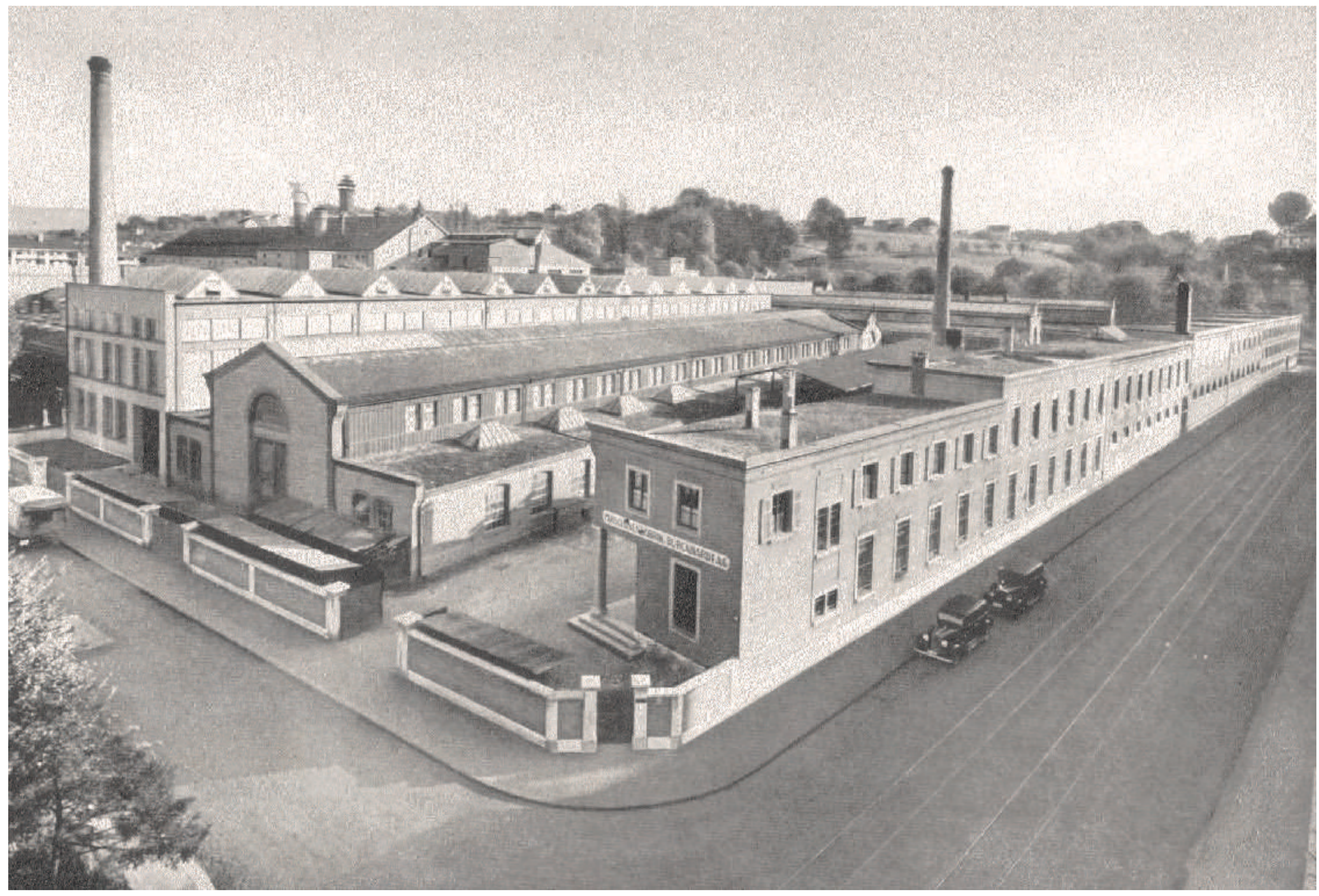
Mr. Bosshart: Solar Silo has a long history, related to Gundeldinger Feld – a former industrial area of the city of Basel. Indeed, the whole area has been renovated and transformed into a multipurpose district adopting the sustainability concept in a wide and holistic perspective, ranging from energy to cultural aspects. It is worth considering that re-building the whole area would have meant a lot of embodied energy, so we tried to find a balance, including economically, for the entire area. Therefore, step by step, the entire site has been renovated, using thermal insulation, good-energy-performance glazing, while also considering water recycling.
Ms. Müller: For instance, we decided to re-use some existing materials (e.g. cladding for the external elevator and the kitchen) and to integrate solar energy into the existing building envelope.
Ms. Müller: The original purpose of a silo was to stock coal needed for heating the entire area. Therefore, the building became a symbol for the transition from fossil fuels to renewables for the whole area - thanks to BIPV, that can be seen by visitors to the site.
In the past, architects had to convince people to choose BIPV, but today this is changing.
Some good examples of integrated BIPV in façades are needed to create a picture of the possibilities in people’s heads.
In this building, the glass of the coloured BIPV modules was designed not to reflect solar light so that there would be no glare effects. We received positive feedback regarding the aesthetics of the building and the modules.
Some people wondered what kind of material we used on the façades, they don’t recognize it as PV!

Decision-Making and Process

The Solar Silo building is part of the former industrial site "Gundeldinger Feld" in Basel that represents a sensitive area of about 12.700 m^2. The discussed industrial area was bought by Gundeldinger Immobilien AG, then, in 2000, the responsibility for the redevelopment of the site was handed over to Kantensprung AG.

For the redevelopment of this area, architects and project developers were required to be capable of embracing a social vision to shape the interactions of work, culture and leisure in a densely populated area.

Moreover, from the beginning, Gundeldinger Feld was recognized as a pilot project of the 2000 Watts Society (www.2000-watt.bs.ch) and the renovation of the district was pursued in accordance with sustainable neighbourhood development.
Every year, Kantensprung AG invests more than 200.000 CHF in energy economy measures to renovate buildings gradually.
Photovoltaics has been integrated into the envelope of the Solar Silo both to provide a visible sign of the shift from fossil fuels to renewable energy and to pursue the objectives of the 2000 Watts Society thanks to renewable energy production.
This project was awarded with the Swiss Solar Prize 2015 in the "Renovation" category.



17-03. Historical picture of the Gundeldinger Field.

17-04. The Gundeldinger Field today.

Building / System Integration

Formal Integration

In this building's envelope, BIPV systems have been designed as façades and roofs using modules with four different colours (gold, grey, green and blue). Indeed, the Kromatix® modules are characterized by a coloured coating on the inner surface of the outer glass that makes the modules appear as matte panels where the PV cells are hardly recognizable from a long distance. Furthermore, the dimensions of the BIPV modules on the façade have been optimized in order to obtain only a few customized sizes, considering the existing modularity and the geometrical aspects and constraints of the façade. On the other hand, the BIPV roof has been constructed using standard module dimensions but the resulting effect is similar to a mosaic, thanks to the combination of different colours.

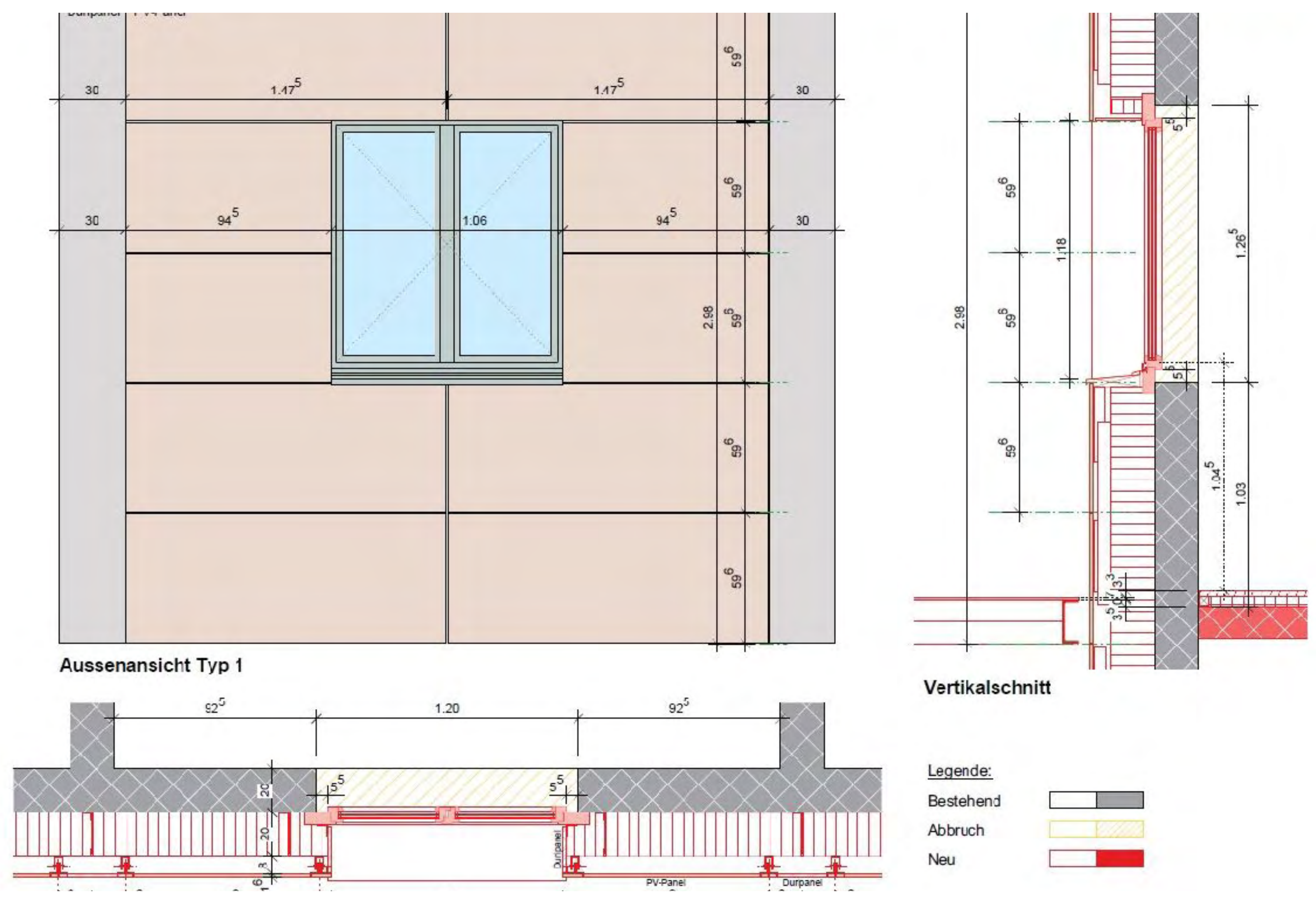
Energy Integration

The BIPV modules have been installed to produce electricity to be used directly for reducing the electricity demand from the grid. In fact, the BIPV system is able to cover about 37% of the total energy demand of the building. Moreover, as an R&D project, each BIPV module of the roof is monitored and the whole PV system is combined with a second-life battery energy storage system for studying how to better optimize self-consumption of electricity in the area.

Technological Integration

The BIPV modules have been used as building materials for both the building's façades and the roof. Indeed, they represent the cladding elements of the ventilated façades that have been constructed to improve the thermal energy behaviour of the existing envelope that was made of concrete. The façade modules have been mounted by means of metal mounting back-rails and fixed by small clamps on the long edges of the modules. Similarly to the façades, the roof's modules are used as large slates creating a water-bearing layer of the ventilated roof that has been created with a wooden substructure on the thermal insulation layer. In both cases, the air cavities behind the BIPV modules represent an advantage for the thermal-hygrometric behaviour of the envelope and for the energy performances of the modules.

17-05. Mounting of the BIPV façade.



17-06. Technical drawings of the BIPV façade.


17-07. Bird’s-eye view of the mosaic BIPV roof.


17-08. Detail of the façade PV cladding with hidden solar cells.


17-09. North BIPV façade.


17-10. Customized BIPV modules for façade.

Finance

For this R&D project there is not a pre-defined business case. Instead all implemented renovation measures have been adopted step by step, considering also the economic aspect of sustainability. For instance, existing building materials have been reused to reduce both investment costs and environmental impact.
This building project is promoted as a pilot project by the Office of Environment and Energy of the Canton of Basel City and the Federal Office for Energy and, specifically, the former supported this pilot project with a funding for coloured BIPV modules.

Lessons learned

As an R&D project, this pilot BIPV building is offering the opportunity to continuously learn from the interplay of electricity production, consumption and storage. The installation of BIPV modules on the Solar Silo, indeed, has been equipped with many sensors, aimed at evaluating the real power output of each single module.
This is allowing us to record the performances of the differently coloured modules over time and compare their real electrical behaviour with the declared values.

17-11. 2nd-life storage system installed in the basement of the Solar Silo.

17-12. Solar Silo environment.

Residential Buildings

Student Housing, Slagelse (DK)

Project data			
Project type	Renovation		
Building function	Residential building - Student housing		
Integration system	BIPV in façade and balustrades		
Location	Ingemannsvej 35, Slagelse		
Architect	KANT arkitekter	Year	2017
BIPV system data		**Producer data**	
PV modules	Standard (balustrade custom-made)	Producer	Komproment and Gaia Solar A/S
Solar technology	Monocrystalline silicon	Address	Jellingvej 11, 9230 Svenstrup
Nominal power	20 kWp	web	www.komproment.dk
System size	150 m^2 façade + 40 m^2 balconies		
Module size	n.a.		
Orientation	South		
Tilt	90°	Author/editor	Karin Kappel

Student Housing, Slagelse (DK)

18-01. BIPV façade.


18-02. Uffe Bay Smidt.


18-03. Johanna Rossback.

Interview with KANT Architects, partner Uffe Bay Smidt and architect Johanna Rossback.

Challenges
The task was to transform a former school building from the 1970s into 144 modern student housing units. The building had to meet the current requirements for energy efficiency and the solutions involved installing PV panels on the flat roof. At the same time, it turned out that there were damp issues in the brick façade that were not fixable. As a result, it became necessary to create a new building envelope. This opened up for the potential to think holistically and more ambitiously in terms of an integrated electricity-generating façade with BIPV.

Proposals
We could either have a glass screen mounted on the existing façade, or a new façade using slate or tile shingles mounted on the exterior of the current façade, which could be insulated. The first solution had issues in relation to fire safety, overheating and operation: how does one maintain a façade that actually consists of two façades? The other solution was much easier from a maintenance point of view. The challenge here was matching the PV module size to the slate modules and the current façade division.

Cross-disciplinary dialogue.
In a cross-disciplinary collaboration between the architect and the manufacturer, we created the integrated solution that - besides being functional and aesthetically pleasing - could also act as a demonstration model.
The most important aspect to consider when deciding was, that we wanted thoroughly tested solutions that were also well-integrated architecturally and quick to price.

Experiences
Standard PV modules are rigid and of fixed sizes that are difficult to match with existing buildings. New buildings can be planed according to the various components but with existing buildings, it can be difficult to make the PV modules to fit without a number of adaptations which add extra costs. Therefore, we believe it is important to continue to develop this area so that more flexible PV components become available. In that case, it would eliminate one obstacle for working with BIPV.

Decision-making
A dedicated client wanted to teach the next generation, the young people living in the student housing units, about solar energy. The architects wanted to create an overall concept which included BIPV.

Process
The process was a cross-disciplinary collaboration between architects and manufacturers. By working together they developed the integrated solution. As the project had already proceeded quite far into the construction process, it was possible to set the exact prices along the way - something that would not have been possible during the consultancy phase. All the parties involved, throughout the entire process, took ownership of the project. This was one of the driving factors that made it possible to develop a sustainable and integrated solution.

18-04. Apartments after the renovation.

18-05. Slates and solar slates.

18-06. Apartments before the renovation.

Proposal 1 - Glass façade.
The first proposal involved placing a glass screen with PV on the current façade.
This raised issues that were related to fire safety, overheating, construction, yield, and operational and maintenance issues.
It was particularly the latter which led us to consider how one would maintain a façade that was in effect two separate façades: one of slate and one of glass.

18-07. Proposal 1 - Glass façade.

18-08. Proposal 2 - Slate façade.

Proposal 2 - Slate façade.
The second proposal was a more traditional solution, with slate or tile shingles mounted on the exterior of the original façade which could then at the same time be re-insulated. It was a standard façade system with PV integrated. It was robust and easy to maintain. The challenges associated with this solution were mostly about clarifying the construction-related issues.

Building / system integration
The façade is made of natural slate, and it is divided into sections that make it possible to replace some parts of the façade with photovoltaic modules.
The 200 m^2 photovoltaic modules are integrated as small horizontal bands in the façade. They are installed at the same stage of the work as the rest of the façade in a plug-and-play system with visible fixtures.

The natural slate is secured by two stainless steel slate hooks, and their colour makes them almost invisible among the rest of the façade. This system is built such that defective parts of the façade and photovoltaic panels can be replaced quickly and efficiently, if necessary.
40 m^2 of glass panels integrated with photovoltaics serving as a balcony balustrade on five balconies have also been installed.

18-09. Semi-transperent modules in the balustrades.


18-10. BIPV façade.

Business Case

Finance

The Social Housing Organisations in Denmark provide inexpensive housing as the buildings are built with government support and the rent is costs-related.
All the social housing associations make payments to a fund, Landsbyggefonden, which offers loans and subsidies for renovation works by the individual housing association.
The renovation of the student housing including PV, received funding from 'Landsbyggefonden' and the rest of the cost is paid for by the tenants' rent.

Lessons learned

With existing buildings, it can be difficult to make the PV modules to fit without a number of adaptations which add extra costs. It is important to develop more flexible modules to make integration of PV into buildings easier.
Co-operation with the manufactures is also important to develop architecturally and economically well-integrated solutions.

Single family house, Ulestraten (NL)

Project data			
Project type	Renovation		
Building function	Residential		
Integration system	90 m² roof		
Location	Ulestraten		
Architect	BEAUsolar	Year	2016
BIPV system data		**Producer data**	
PV modules	Solar Frontier 170 Wp modules	Producer	BEAUsolar
Solar technology	Standard thin-film (CIGS) modules	Address	Mauritslaan 49, Urmond (NL)
Nominal power	12 kWp	web	www.beausolar.nl
System size	90 m²		
Module size	997 x 1257 mm²		
Orientation	Southeast		
Tilt	30°	Author/editor	John van Oorschot

Single family house, Ulestraten (NL)

19-01. Front site view of single family housing covered by full roof BIPV.

Interview with BEAUsolar, represented by Mrs Caroline America (Marketing) and Mr Raoul Comuth (Director).

The private building-owner of this BIPV case project, a scientist and entrepreneur, wanted a sustainable investment and was already convinced by the application of PV. The investment was in particular motivated by the relatively high energy consumption due to the heat pump of the swimming pool and the electric car. At the same time, there was a need for roof renovation because the roof deck consisted of asbestos-containing sheets. The roof has been renewed with standard thin-film solar (CIGS) panels which are part of the building-integrated pitched roof solution, i.e. a whole roof BIPV solution.

Mr Comuth lists three scenarios in which potential clients could become interested in this solution: building-owners who face an 'renovation anyway' of the roof, building-owners who must create a new roof in the case of a newly constructed dwelling, and building-owners who want to apply BIPV for aesthetic reasons in contrast to a traditional BAPV system. Typically potential customers are already acquainted with building-integrated PV solutions.

In addition, Mrs America addresses several arguments to invest in a whole-roof BIPV solution. First of all, investments in BIPV often links to sustainability and a green image because of the usage of solar energy. Timing of the decision to invest with 'renovation anyway' of the roof stimulates the application of BIPV. There is now no need to work on the roof twice with respect to installing PV and replacing the roof cover. Third, BIPV is more aesthetically appealing than BAPV. BEAUsolar offers an unique 'whole-roof' solution consisting of a completely plain roof surface. The solution is unique when it comes to the use of dummy modules in places where PV modules are not possible. The BIPV roof can be installed relatively quickly which also could be considered as an advantage. Finally, the PV system is financially competitive with a traditional roof and PV modules that are added to the roof structure (BAPV).

19-02. Mr. Raoul Comuth, Director BEAUsolar

19-03. One side of the roof is covered by BIPV while the other side is covered by tiles.

Decision-making.
Going beyond sustainability considerations, there was a need for a roof renovation. In combination with relative high electricity costs this motivated the adoption of BIPV. BEAUsolar, the installer of the PV system, offers a one-stop-shop solutions involving the design, engineering and installation to private building-owners. An architect or building contractor is not involved in the process.
Onsite labour was subcontracted and included removing (parts of) the existing roof and installing the BIPV.

Process.
On average the planning takes about four to five weeks after which the work on-site will be executed within four days. The process can be divided into eight steps. First, the energy consumption and energy requirements for the next two years are determined and the condition of the building structure is examined. During the second step a suitable PV module based on energy requirements and roof surface is selected and a budget indication is prepared. The budget is discussed with the homeowner(s) (step 3). After commissioning the project (step 4), the planning stage (step 5) takes off. During step six, the existing roof cover is removed on-site and a vapour-permeable layer is installed. Also, the aluminium profiles are installed and the dimensions of the finishing and fitting pieces (plastisol) are installed. Where possible, cabling is installed. The finishing and fitting pieces are ordered (plastisol typesetting). Then the solar modules are mounted with clamping strips and connected to the inverter. Finally the installation will be taken into operation.

Building / system integration

Formal integration.
The photovoltaic system is integrated into the roof structure of a detached dwelling and replaces the tiles on the south-eastern section of the pitched roof. On the opposite site of the pitched roof traditional tiles are installed. The BIPV roof has been engineered in such a way that it matches the thickness of the cross-section of the roof section covered with tiles.

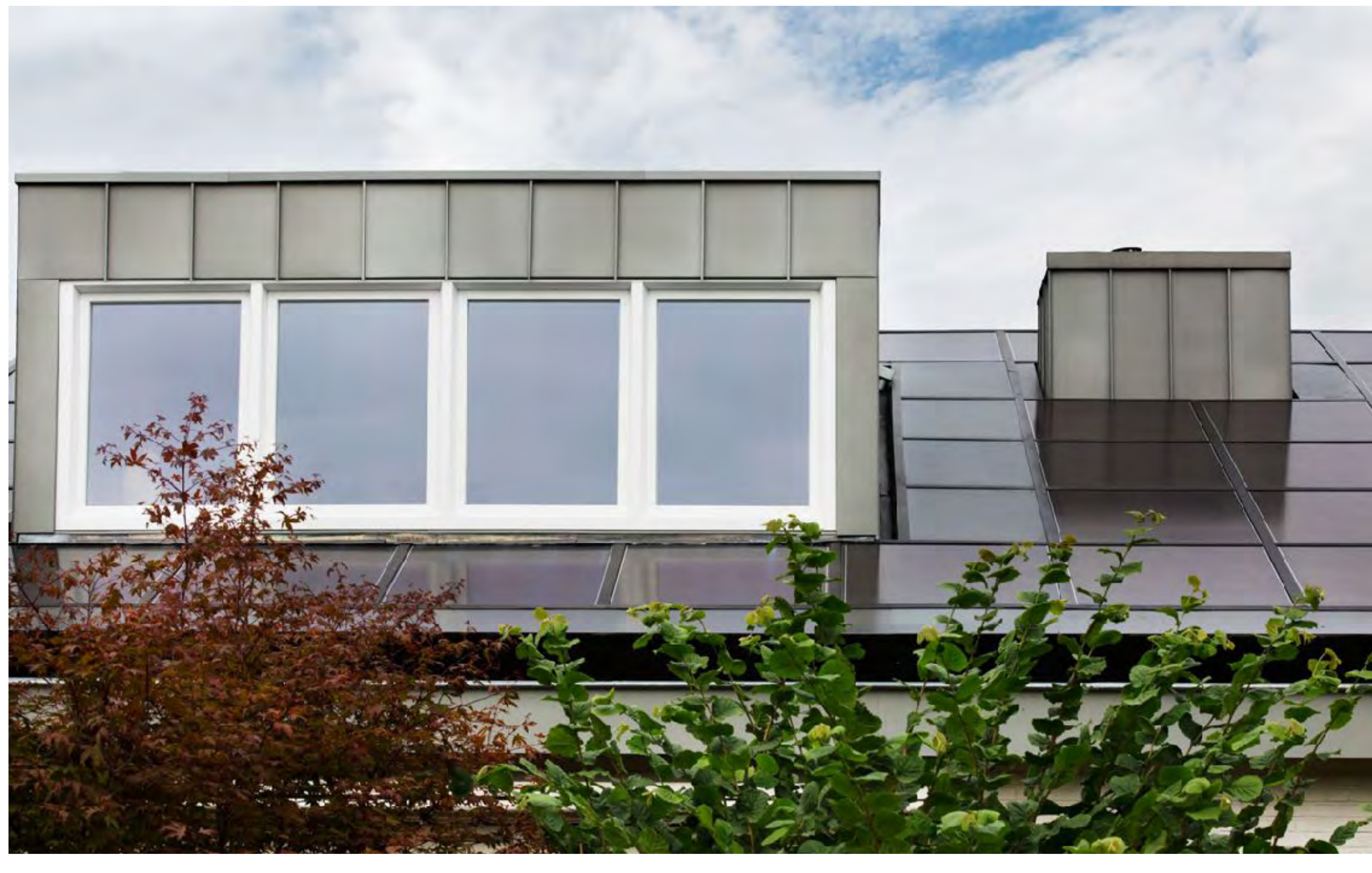
Energy integration.
As a result of the heat pump for the swimming pool and the energy consumption of the electric car, the energy demand is relatively high. The PV system is expected to produce around 10,600 kWh/year.

Technological integration.
In total, 92 Solar Frontier standard thin-film modules (170 Wp each), where installed on three roofs. The modules are mounted with aluminium frames designed and produced by BEAUsolar. Weather-tightness is ensured by three components. A water-tight, vapour-permeable layer is installed on top of the existing roof deck. The mounting profile includes an integrated gutter system (second waterway). Finally, the solar modules with clamping profiles are primarily responsible for the weather-tightness of the dwelling. Taken together, the PV system encompasses a modular, flexible whole-roof system. The modules are naturally ventilated due to the distance between the modules and the roof. The cavity space can be adjusted to ensure a neat connection with the adjacent roof surface.

Finance.
The project was installed on time and within budget. The investment was 250 €/m², which is comparable to other BIPV solutions.
The expected payback time of the investment is about 7-9 years, whereas about five years applies for BAPV. There were no economic restrictions or any kind of subsidy involved regarding the BIPV in this particular project.

Two additional economic incentives apply to this case but were not decisive in adopting the whole-roof BIPV. First, it has been calculated that energy costs will increase significantly in the coming years due to an increase in energy taxes. In addition to VAT, an energy tax and a Sustainable Energy Allowance must be paid over the costs for gas and / or electricity (the revenues from the Sustainable Energy Allowance are invested in energy efficiency by the Dutch government). Secondly, there is a net metering scheme that raises the value of excess electricity to the same level as self-consumption.

BEAUsolar is considered a technology start-up and the building is a showcase of innovative BIPV which gains publicity. This type of building owners is considered a niche market in the Netherlands and the projects conducted in this segment are used to improve the architectural design of the BIPV installation. The design is considered a key aspect to further upscaling BIPV in the private housing sector in the Netherlands.



19-04 Design solution connection BIPV and dormer.

19-05 Basic detail of the roof integration.

19-06. Street view of single family housing covered by full roof BIPV.

Lessons learned.
BIPV turns out to be competitive due to the combination of “renovation anyway” and installing BAPV.
The BIPV needs to be offered at the right time, combining the demand for roof renovation and PV.
One-stop-shop: having a single entity that is responsible for the design, engineering and installation of the BIPV is successful.
The all-black, single-level design of the roof surface is preferred over BAPV.
Despite a variety of possible obstructions in the roof surface (roof ducts, skylights, and dormer windows) the modular design offers flexibility to cover several roof typologies.
The BIPV is installed within 4/5 days. The lead time of the project, design, engineering and construction can be limited to 6 weeks.

To get the BIPV accepted and adopted in the market, it was learned that because of its innovative nature, potential clients need to be convinced of its maturity. First of all, detailed technological design specifications show that the BIPV is sufficiently designed and ‘matured’. Next, showcases not only create awareness of BIPV but also help potential clients to understand how the BIPV appears. It is equally important to frame the BIPV in the correct way: ‘integrated PV’ versus ‘aesthetic electricity-generating roof covering producing energy’. In addition, it remains challenging to convince homeowners to adopt and install BIPV. There is a lack of clear understanding about cognitive decision-making processes of homeowners. Installing BIPV initiated by a homeowner can have different motivations and financial schemes. The adoption of BIPV can have different motivations and financial schemes such as subsidies and energy-saving loans are not always decisive. Market consultation has been mentioned to increase the understanding of individually based decision-making and bias against BIPV.

19-07 Design solution connection BIPV and overhanging eaves.

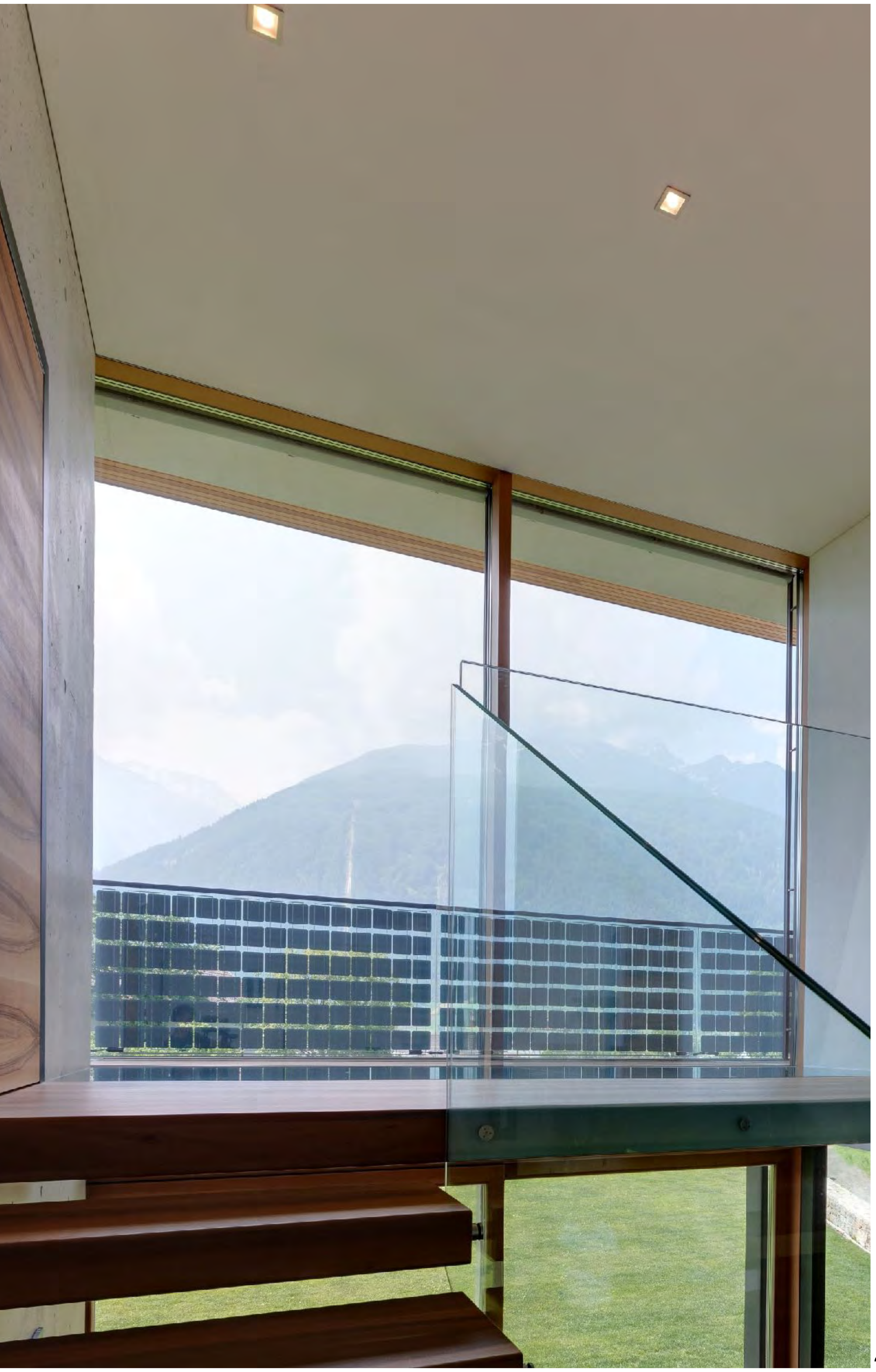
19-08 Design solution connection BIPV and eaves (top-view).

Single family House, Lasa, Bolzano (IT)

Project data			
Project type	New construction		
Building function	Residential		
Integration system	BIPV as semi-transparent balustrade		
Location	Via Venosta 70/a, 39023 Lasa		
Architect	Building owner	Year	2012
BIPV system data		**Producer data**	
PV modules	Custom-made	Producer	EnergyGlass Srl
Solar technology	Monocrystalline silicon	Address	Viao Domea 79, Cantù, Como (IT)
Nominal power	1.3 kWp	web	www.energyglass.eu
System size	3,700 modules, 13 m^2		
Module size	1,120 x 1,905 mm, 1,120 x 2,005 mm		
Orientation	West, south, east façade		
Tilt	90°	Author/editor	Laura Maturi, Jennifer Adami

Single family House, Lasa, Bolzano (IT)

20-01. BIPV balustrate.



20-02. View of the photovoltaic balustrade from inside.

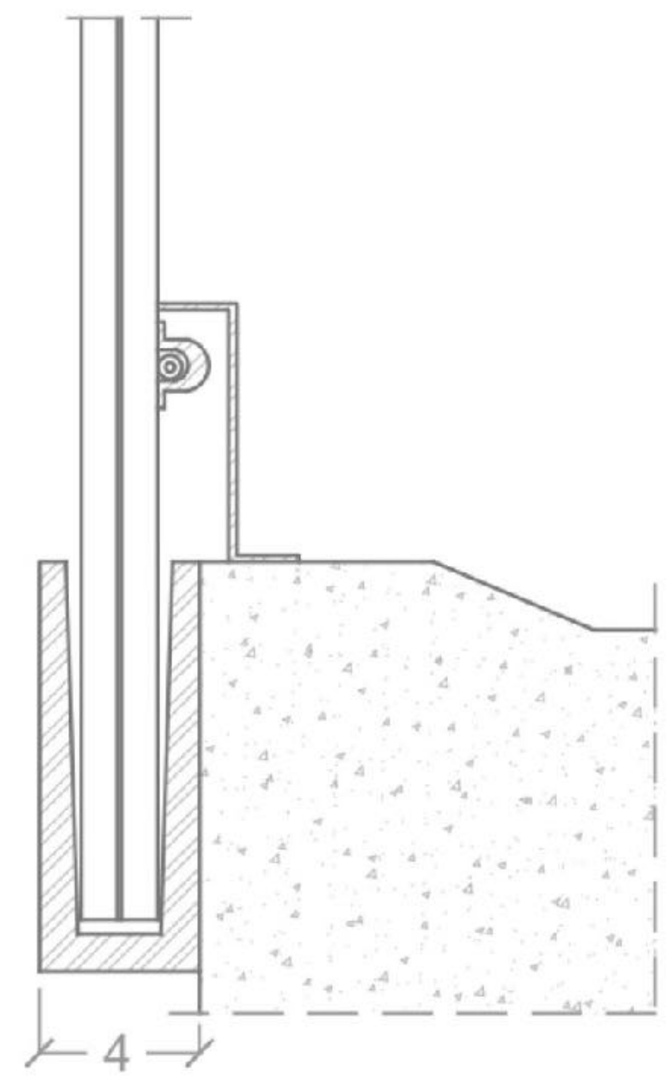
Interview with the building owner.

Challenges
Early in the planning phase, we decided that the balcony design should not affect the lightness of the glass façade, it should provide sufficient privacy to the bedrooms on the first floor and it should fit harmoniously into the whole building shape. Because satin-surfaced glass did not meet our aesthetic requirements, we decided to experiment with printed glasses for the transparent part and the prefabricated BiPV modules (Solarwatt M140-36 GEG series). Unfortunately, we were not satisfied with either the value of the printed glass or the aesthetics of the prefabricated BIPV modules. So we called for offers by ertex solar and Energyglass regarding custom-sized solar modules which could also be attached by a Q-railing frameless system. With the technical proposal and economical offer (which included the delivery of the modules) from Energyglass we were then definitely satisfied.

Aesthetics
We are very satisfied with the aesthetic solution; the solar modules meet the aesthetic purpose for which they were deigned. If I could design from beginning the project, I would no longer mount the balustrade glazing vertically, also vertical, but slightly tilted to the inside (10-15°). This would fit better with the trapezoidal shape of the house and the annual electricity generation (currently about 850 kWh) would increase by approximately 20-25%. (PVGIS calculator)

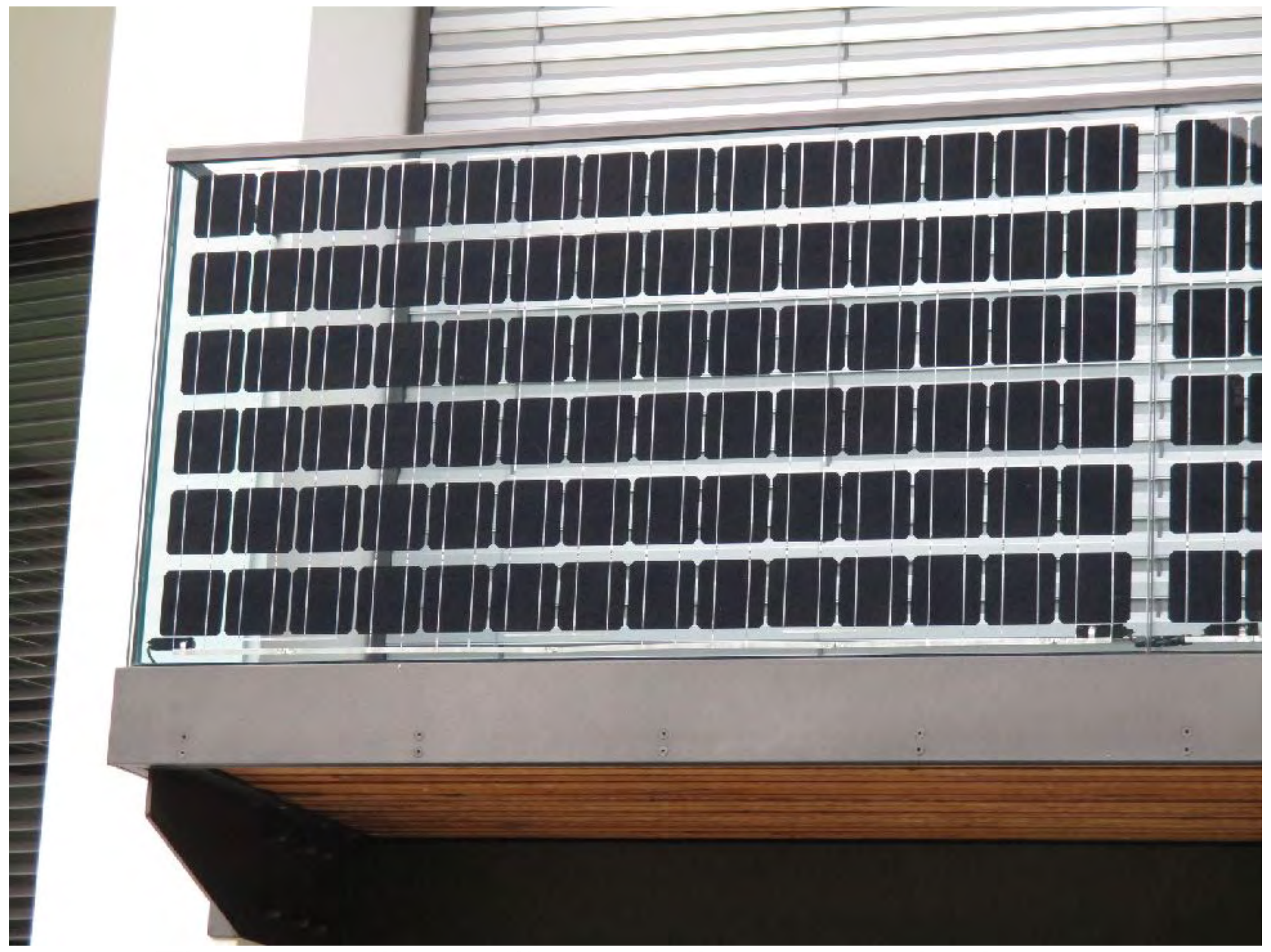
Decision-making
The owner decided to integrate photovoltaic modules into the balcony balustrades when the building construction was almost completed. Primarily, the PV plant is a useful solution to supply the heating boiler energy demand, that was previously heated by a pellet furnace. Secondly, the owner wanted to use a semi-transparent shading device to partially obstruct the view into the large windows, initially thinking about a satin-surfaced or screen-printed glass solution. The final BIPV solution was found by visiting an exhibition of PV products, where the building owner compared different solar glazing solutions and found the best one.

Process
In 2007, the chartered building surveyor Coletti Renato was commissioned by the owner to design the house. The construction works took about 4 years. After comparing different quotes of PV manufacturers, EnergyGlass Srl was chosen to supply the modules and the BIPV system design. EnergyGlass Srl also managed the bureaucracy associated with receiving government incentives. The owner installed the system himself with the help of specialists. Later, the building owner mounted additional PV modules on the building roof in order to supply the total boiler energy demand.



20-03. Technical detail of the 'Q railing' mounting system.

20-04. Detailed view of the junction between module cables.



20-05. The crystalline cells partially protect the large windows against outside observers.

20-06. The semi-transparent balustrade allows the landscape to be enjoyed from the interior.

Building / system integration

Formal integration

The PV system is integrated into a 2-storey residential building located in a small village in Val Venosta, along the Adige River. It consists of semi-transparent glass modules installed in the glazed balcony balustrades on the first storey. The modules represent a barrier that protects the large windows characterizing the main building façade, without blocking the mountain landscape view from inside (Figure 2). Their pattern highlights the building's horizontal development. Due to the refined design, the BIPV system combines the electricity generation functionality with an aesthetically pleasing appearance.

Energy integration

The BIPV plant was designed to provide a electricity yield of around 800 kWh. Its electricity output, together with the production of additional PV modules located on the roof (1 kWp), supplies the energy demand of a connected PV heater (Refusol), which is used to heat up tap water with an immersion heating rod in the house's hot water tank. The two PV plants form a stand-alone system which is able to meet the whole building's thermal energy demand.

Technological integration

The BIPV plant is made of 6 frameless modules (EGM 84-90 ST), which were assembled using laminated safety glass (10 + 10 mm). The PV cells between the glass panes are spaced apart leaving gaps of 2–5 cm, thus making the modules semi-transparent (37–38%). The modules are connected to internal bypass diodes, which do not require the modules to be divided into sub-modules. Two junction boxes are located at the bottom of each glass panel. The PV mounting system (Q railing easy glass slim) does not require holes in the modules because the laminated glass is wedged into a 120 mm metal rail all along the balcony which also guarantees the water drainage.

Finance
The photovoltaic system plays an important role in holistic view of the building, they are immediate recognizable for the observers of the house. The modules are semitransparent and customized. As a consequence, the whole BIPV system cost was quite appreciable. Nevertheless, the house owner decided to install the system to meet the sustainable energy target he had set for the heating of DHW and generation of electricity.

Lessons learned
The building owner carried out a detailed evaluation before deciding to integrate the photovoltaic technology into the glazed balustrade. He wanted something that could partially conceal the windows, so he also considered installing satin-surfaced or screen-printed glass. An economic assessment revealed that the glazed PV could be quite competitive with the glass. Aesthetically, the same striped texture could be achieved. Therefore, the photovoltaic option was preferred by the building owner. The low amount of electricity generation and the lack of a suitable storage solution on the market, in 2012, led the owner to connect the photovoltaic plant to the PV heater consuming the generated electricity in a different way. The current innovation level reached on the photovoltaic market allowed the building-owner to re-think other possible solutions, such as using an inverter with integrated energy storage. This confirms that the energy integration aspect is becoming more and more important in BIPV.

Due to the low annual performance, the system has been designed as an island system for DHW. Unfortunately the annual real output of 850 kWh_{te} was insufficient to heat the water for for a 5 person household during the period from April to October. Therefore, 30 uni-solar modules PVL-136 power bond were installed in a second phase. Each single triple-junction solar module is mounted with an adhesive onto a prefabricated aluminium roof element. Thanks to an additional 1000 l chiller, the demand for DHW can be met completely during the period April to October. The system has been running since 2011/2012 without any problems.


20-07. BIPV system as the central component of the main building façade.

Social Housing Apartment, Best (NL)

Project data			
Project type	New construction (Urban renewal)		
Building function	Residential buildings		
Integration system	Façade		
Location	Best (NL)		
Architect	NB Architecten	Year	2018
BIPV system data		**Producer data**	
PV modules	Stion CIGS solar (frameless) modules	**Producer**	EigenEnergie.net BV
Solar technology	Standard thin-film (CIGS) modules	Address	Spaarpot 20, 5667 KX Geldrop (NL)
Nominal power	250 kWp	web	www.eigenenergie.net
System size	750 m^2 façade + 500 m^2 balustrades		
Module size	656 x 1656 mm^2		
Orientation	Three façades of the apartment buildings		
Tilt	90°	Author/editor	John van Oorschot

Social Housing Apartment, Best (NL)

21-01. Two apartment buildings with renovated façades and BIPV.

Interview with Mr. Olaf van Dijk, project manager of social housing association ‘THUIS.

“THUIS” social housing association developed an energy efficiency policy for their building stock. This policy guides decision-making regarding newly built dwellings and apartments and the renovation of existing housing. The energy efficiency policy includes the requirement that newly built housing units are to be “constructed as zero energy buildings.

“THUIS owns several 5-storey apartment buildings which require deep-renovation. For the two worst apartment buildings, the housing associations faced several investment alternatives. At first the housing association considered deep-renovation towards the (near) zero energy standard of newly built housing. However, it turned out that newly built quality could not be met with respect to building acoustics and therefore it was decided to demolish and replace both structures by zero-on-the-meter, 5-storey apartment buildings.

Examples of zero-on-the-meter apartment buildings in the Netherlands are scarce in contrast to zero energy single-family housing. Photovoltaics integrated into the roof in combination with heat pumps are the key technologies with respect to zero energy housing. However, in contrast to single-family housing, photovoltaics on top of apartment buildings is not sufficient to meet the energy consumption of the apartments.

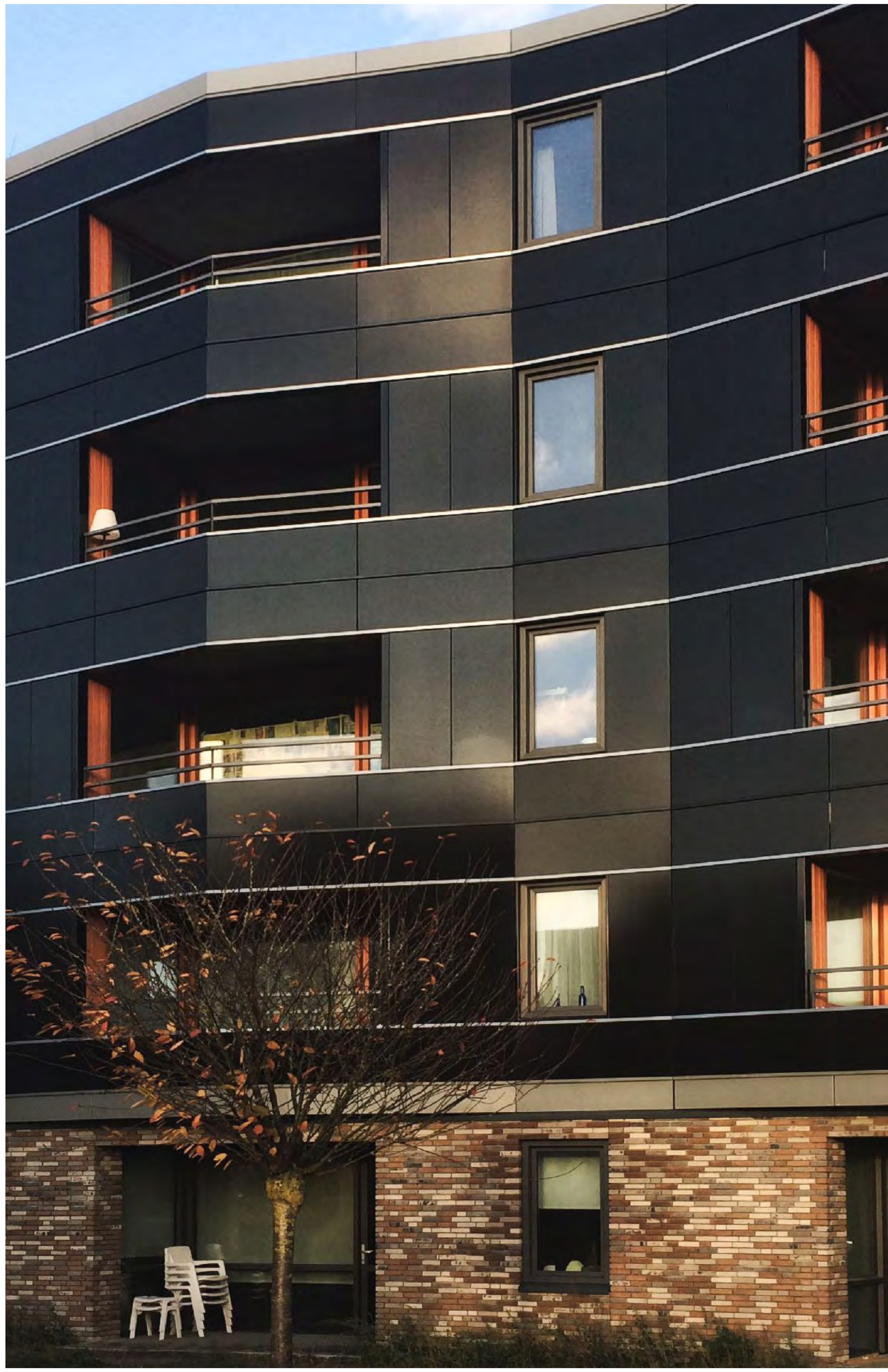
For the replacement of the 5-storey apartment buildings photovoltaics has been integrated into the façade on all sides of the building to compensate for the insufficient electricity generation from the roof alone. To reduce the construction costs, the façade was designed in such a way that standard CIGS modules could be used. As a result the façade is characterized by a zigzag form.

The adoption of a zero-energy building policy and the adoption of BIPV integrated into the façade in particular is motivated by the energy efficiency policy of the social housing association. However, several complementary innovations were required to sustain adoption, involving both technological and administrative innovations. Firstly, “THUIS” invested in the development of the required organizational capabilities to create a knowledge base among the employees. Besides that, slack resources were made available and the procurement policy was reconsidered. In order to select supply chain partners with specific requirements to succeed within this innovative project, selection criteria are required that go beyond just the lowest price.

21-02. Mr. Olaf van Dijk, projectmanager THUIS.

Decision-making.
The professional client of this BIPV case project, a social housing association, wanted a sustainable investment and was already convinced by, and had experience with, the application of PV. The investment was in particular motivated by the energy efficiency policy of the social housing association. BIPV integrated into the façade is part of the design of a zero energy apartment building. Therefore standard thin-film solar modules are integrated into three façades of the apartment buildings.

Process.
Based on a partnering concept the project was completed in close collaboration with the architect, the contractor and several key suppliers. Because of the immaturity of the market for zero-on-the-meter apartment buildings, this project is considered a demonstration project. Therefore, as mentioned by several stakeholders, integrated project organization was required to design, engineer and construct the project. Traditional procurement is not conductive to close collaboration between stakeholders and is therefore considered to be a key obstacle to the construction of zero energy buildings. In this respect, further innovation is required to optimize the construction process of zero energy projects.



21-03. BIPV façade with standard modules.

21-04. Because of standard dimensions, the PV modules are installed in a zigzag shape.

21-05. Northeast façade with partly BIPV (left side).

21-06. The modules are mounted on an aluminum support structure.

21-07. The outer layer of the traditional cavity wall is replaced by BIPV.

Building / system integration

Formal integration.
The photovoltaic system is integrated into the façade structure of two apartment buildings (48 apartments). The PV system replaces the outer layer (masonry) of the cavity wall. The PV system was engineered in such a way that standard CIGS panels could be installed.

Energy integration.
The heat pump installed in every single apartment in combination with the installed BIPV system installed provides an “energy budget” which covers the energy consumption of each apartment.

Technological integration.
About 750 m^2 CIGS modules are integrated into the façade and another 500 m^2 CIGS modules are integrated into the balcony balustrades. The modules are mounted with aluminium frames developed by Energywall. On the roof of the apartment buildings, additional PV modules are installed.

21-08. Façade in the late afternoon.

21-09. Balconies are integrated in the floor plan for an optimal facade design.

Finance

Guided by internal energy efficiency policies, the housing association decided to invest in two zero-on-the-meter apartment buildings, which include photovoltaics integrated into the façade of the buildings. The buildings are depreciated over a period of 50 years. However not all the investment costs are covered by the project. Financial resources were made available by the housing association to construct a demonstration project. At least 50% of the additional investment in sustainability needs to be covered by rent and the Energy Performance Fee. The Energy Performance Fee has been introduced by the government to overcome the split-incentive problem, i.e. the gains on the energy bill of tenants are paid by a fee to the social housing association to cover the investment in energy efficiency technologies.

Lessons learned

The alternative to a zero energy apartment building including the photovoltaics installed in the façade in this project, would be an ordinary apartment building constructed according to the building code. Because of the infancy of zero energy buildings in general and the application of photovoltaics integrated into façades, demonstration projects are considered to be vital to their further uptake.

The following key factors affected the case:
1. Energy efficiency policies stimulated the uptake of sustainable technologies by social housing associations. However, energy efficiency policies tend to differ among social housing associations as a result of local conditions.
2. Lowest price procurement policies are not conducive to partnering concepts and therefore hinder the uptake of sustainable technologies.
3. Financial resources to invest in sustainable technologies – often linked to learning costs – are stimulating the uptake of sustainable technologies
4. Despite the energy performance fee it remains challenging to communicate with tenants about the fee. Moreover, the legal implications of the energy performance fee are not fully understood by either social housing associations or the housing industry.
5. A lack of knowledge about the legal conditions and subsequent decision-making processes within the social housing sector complicates the collaboration between social housing associations and the housing industry.
6. The social housing association involved in the case project invested in building organizational capabilities, i.e. the knowledge and skills, necessary to adopt and implement sustainable technologies in the project.

21-10 Construction detail with cavity and thermal insulation.

Skarpnes Village, Arendal (NO)

Project data			
Project type	New construction		
Building function	Residential building		
Integration system	Opaque gable roof		
Location	Øvre Fagerhei, 4823 Nedenes (Arendal)		
Architect	Ole Bachke, Rambøll Norge AS	Year	2015
BIPV system data		**Producer data**	
PV modules	Sunpower all-black integrated	Producer	SunPower modules, SolRif mounting system
Solar technology	Monocrystalline silicon	Address	77 Rio Robles, San Jose, CA95134, USA
Nominal power	7.36 kWp	web	us.sunpower.com
System size	32 modules, 40 m^2		
Module size	1583 x 792 mm^2		
Orientation	Southeast (2 houses), Southwest (3 houses)		
Tilt	32°	Author/editor	Anne Gerd Imenes

Skarpnes Village, Arendal (NO)

22-01. BIPV roof at Skarpnes.

22-02. The Skanska project manager, Mr Roald Rasmussen.

Interview with Mr Roald Rasmussen, project manager from Skanska Norway (owner, developer and builder of the Skarpnes zero energy housing development), and Mr Ole Bachke, project leader from Rambøll (sub-supplier company for architectural design).

Mr Rasmussen: It all started with a housing development in Arendal (South Norway) where we built eight new residential buildings according to the Norwegian passive house standard NS 3700. As we were planning for the next housing development, we were invited to hold a presentation for the national research centre on Zero Emission Buildings (ZEB, www.zeb.no). As a result, it was decided that Skanska Norway should build the first zero-energy housing development in the country.

Mr Bachke: This project has been both interesting and educational. The requirements challenged us to think in new ways. The architects tried to combine a modern expression with the need to fit in with the existing settlement, consisting of traditional wooden houses. The houses therefore have gabled roofs. The walls are thick with hidden integrated technical solutions. As much as possible of the energy and material needs are sourced locally, using wood, low-carbon concrete and recycled gypsum, ground-well heat pumps for hot water and PV for electricity.

Mr Rasmussen: We wanted to build top modern houses and in addition gain new knowledge about the grid interaction and what it feels like to live in zero energy houses. These aspects are investigated in the two national research projects «*Electricity Usage in Smart Village Skarpnes*» and «*Evaluation of Buildings with Low Energy Usage, EBLE*». It has been challenging and exciting to be part of this work, and we believe it is important to stay at the forefront of the market development.

Sources:

'Bygger Nordens første boligfelt med nullhus', pressemelding fra Skanska, 04.07.2014 (www.skanska.no).

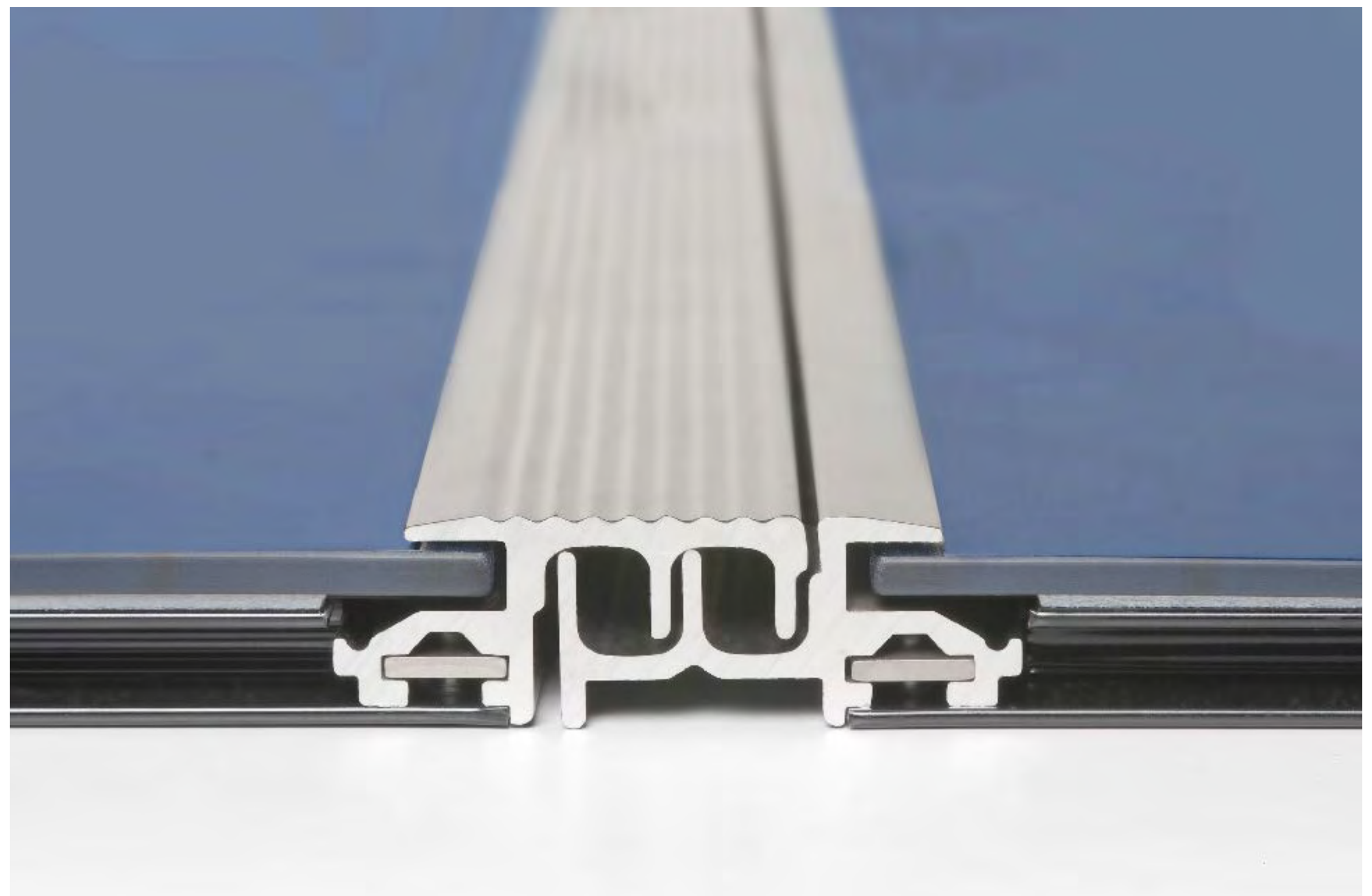
'I Nordens første nullenergi boligfelt i Arendal står strømmålerne stille', news article by Kim Johnsen, Klimapartnere Agder, 20.11.2014 (www.klimapartnere.no)

Decision-making
The initiative to apply a PV system to the building was taken by project leader Roald Rasmussen, in discussions with research leader Marit Thyholt from SINTEF and Tor Helge Dokka from SINTEF/Skanska, who is in charge of the ZEB pilot buildings development. The decision was made because Skanska has a general strategy to be known as a leading green developer. Skanska had already gained positive experience with building passive houses, which were a sales success and had low additontal costs compared to traditional houses. It followed that Skanska wanted to test the 'next step' moving towards zero energy.

Process
The idea was initiated at the concept phase in an early planning stage. After around one year of discussions between Skanska and SINTEF, it was decided to build the Skarpnes houses as ZEB pilots, following the passive house standard but with additional measures to achieve zero energy. The final decision was made when support from Enova (a Norwegian public enterprise promoting energy efficiency and new technology for renewable energy utilization) was approved.
As Skarpnes was a ZEB pilot project, a series of workshops was arranged to evaluate possibilities, criteria and solutions. After the design and technology solutions were selected, the process followed the standard building development process in Skanska, in close contact with the research groups involved.
Initially, the houses were designed with both solar thermal collectors and PV modules. At a late stage, the solar thermal collectors were removed and replaced by extra PV modules as this was considered to be more economical than the added costs and complexity of plumbing required for the solar thermal system.
Building integration of PV was chosen for aesthetic reasons. A gable roof was planned at an early stage to optimize the annual energy output required to achieve ZEB status. Early-stage dimensioning of the BIPV system was performed by the Multiconsult consultancy company (Norway), whereas final stage simulations were performed by the BIPV system supplier Solcellespecialisten (Denmark).
Skanska was responsible for the practical installation, using electricians from the local sub-supplier company, Nedig to connect to the grid. Grid connection and capacity related to the inverter were checked together with the local utility company, and the first house was occupied in December 2014.


22-03. Building site after BIPV installation.


22-04. Mounting of the BIPV modules.


22-05. BIPV module interlock (Solrif).

Building / system integration

Formal integration.
The PV system is integrated into the gable roof of a modern style residential unit that also implements traditional elements such as roof tiles and wooden cladding. The BIPV system is made of black modules replacing conventional roof tiles and blends in well with the dark roof. The building is surrounded by buildings of similar style in a small village, sitting on top of a small hill in scenic surroundings. The Nidelva river passes the hill on its way to the oceanside, which is less than 2 km away.

Energy integration.
The buildings are classified as ZEB-0 houses, which means that over the period of one year, the total balance between energy consumption and energy production should be zero. This is achieved by using 100 meter deep ground wells that are combined with a heat pump system for domestic hot water, space heating and hot fill laundry machines, thick insulation and a heat recovery ventilation system, and an efficient BIPV system calculated to produce almost 7000 kWh/year. The first two years of measurements show that the BIPV system yield is slightly higher than anticipated, whereas the energy consumption is somewhat higher than expected, mainly due to heating loads and individual user preferences.

Technological integration.
The 32 PV modules are of 230 Watt black mono-crystalline silicon modules from Sunpower, which are mounted in-roof using the Solrif XL system from Schweizer. This involves using aluminium profile frames fixed to the substructure of wooden battens on a roof underlay, using special mounting clamps. Water-tightness is ensured using a special interlock of the modules' profile frames and sealing between the overlapping module edges. The modules are naturally back-ventilated due to the distance between the modules and the roof.
There are no objects in the immediate surroundings of the building causing major shading impacts. However, at low solar angles in the early morning or late afternoon some buildings in close proximity may cause shading, and the boards at the end of the roof cast some shade on the end modules.

Carpenter Hans Kristian Sonesen, Skanska:

As I did not have previous experience with PV installations in buildings, it was useful for me to gain new knowledge both from the system supplier and as a learning process during the mounting. We encountered no problems with the installation, the system operates as expected and there has been no need for follow-up. We are very pleased with the result and the aesthetic integration of the system.

Building owner Petter Lindaas:

We had been interested in buying a low-energy or zero-energy house for several years, and were the first owners to move into the Skarpnes village. This was a unique opportunity to get a modern and comfortable home in beautiful surroundings. The aesthetics of the BIPV system is important, and we prefer a uniform appearance where the PV system cannot be distinghuised from the roof itself. Our desire to live in a zero-energy house is twofold; both for environmental reasons and to lower our energy expenses. It gives us great satisfaction to see the reduction in the energy bill each month.

22-06. Skarpnes village.

22-07. Building owner Petter Lindaas.

22-08. Skarpnes zero energy village.

Finance

Since standard modules and mounting products were used, the cost of this BIPV system (i.e. € 2,11/Wp plus installation costs similar to normal roof installation costs) is not much higher than for conventional building attached or ground-mounted PV systems. In today's market, this system represents an economically feasible system with high replication potential.

Lessons learned

The biggest challenge for the building developer was not the project design or building process, but to find solutions that ensured economic feasibility. A slow market in 2014-2015 affected all housing developments in general and was not the best time for selling new ZEB houses, which were a little more costly (10-15%) than conventional houses due to the range of technically advanced solutions employed. Five ZEB houses were sold, where the BIPV system costs represented a small percentage (~3%) of the total overall cost of 4.5 million NOK (536 k€). The house owners expressed great enthusiasm about their energy-friendly homes and suggested that the high building standard should be better marketed to improve sales of new ZEB homes.

Overall, the building developer is pleased with the construction and implementation of the BIPV system and would choose the same solution again. The PV technology integration combines contemporary with traditional design. The all-black PV modules are integrated into the roof as if they were conventional roofing components, blending with the traditional black tiles on the gable roof. The BIPV system performs well in the cold Nordic climate and represents a valuable source of electricity for new low-energy housing developments.

22-09. Skarpnes residential building.

22-10. Skarpnes residential building.

Frodeparken, Uppsala (SE)

Project data			
Project type	New Construction		
Building function	Residential building - Apartments		
Integration system	900 m^2 façade		
Location	Stationsgatan 52, Uppsala		
Architect	White arkitekter	Year	2014
BIPV system data		**Producer data**	
PV modules	Standard Q-Cells (now Solibro)	Producer	Solibro GmbH
Solar technology	CIGS thin-film, 11.8% module efficiency	Address	Sonnenallee 32, 06766 Bitterfeld-Wolfen (DE)
Nominal power	100 kWp	web	www.solibro-solar.com
System size	1181 modules		
Module size	1196 x 636 mm		
Orientation	Curved façade, southwest to southeast		
Tilt	90°	Author/editor	Bengt Stridh, David Larsson

Frodeparken, Uppsala (SE)

23-01. Curved BIPV façade.

23-02. Next to the train station and the city centre.

Interview with architect Mats Egelius (White arkitekter), building owner Åsa Reinsson (Uppsalahem, project manager and in board that made the investment decision) and PV contractor Lars Hedström (Solkompaniet).

Aesthetics

The original design was made with blue silicon cells and customized modules but during the design process, it evolved to black standard-sized thin-film modules with frames. Uppsala is a university city with outstanding research in thin-film solar cells. The CIGS thin-film technology used was originally researched and developed in Uppsala. This was one of the reasons why it was chosen to replace the blue silicon cells by black CIGS. The curved façade fits the surroundings and the black surface of the thin-film modules is not obviously PV to the non-expert eye. In addition, a few customized modules, which are not electrically connected, were needed to fill the whole façade with modules.

Challenges

The curved façade was a challenge for the installation. Thin-film modules were chosen because of their smaller size than standard silicon modules, offering greater flexibility for the construction, so that standard modules could be used, lowering the cost of the façade.

A tolerance of 10 mm in height for mounting 14 modules was needed.

23-03. Architect Mats Egelius - White arkitekter.

23-04. The evolvement of the BIPV façade of Frodeparken. (1) Original design in building permit.

23-05. (2) Revised design with thin-film modules.

Decision-making

The idea of a BIPV façade on this building was raised by White arkitekter when they were hired for the town-planning process of the area. A glass façade was an alternative to a BIPV façade far into the design process. Uppsalahem wanted something that stood out. It was also an owner directive by politicians on the board of the city-owned Uppsalahem to promote renewable energy. The main reasons for the project were profiling and to enhance PV competence within the company.

Process

The design of the façade was elaborated together by White arkitekter, Uppsalahem and Solkompaniet, that had been hired as consultants. After a tendering process the construction company Skanska was given the responsibility for the whole building project, contracting Solkompaniet to do the BIPV installation. It was a very long process with many stakeholders, which often makes it hard to involve PV and especially BIPV later on. The PV manufacturer went bankrupt during the process and it became uncertain whether the order made was still valid.

Building / system integration

Formal integration

The building is located close to the railway station and is one of the ‘entrance buildings’ that are visible on entering the city of Uppsala by train from Stockholm.

Energy integration

The PV electricity is used only for building functions and is not used by the households in the building. The annual electricity generation is around 70 000 kWh. 43% of the PV electricity is self-consumed, which corresponds to 28% of the total annual demand for the building functions, and the rest is fed into the external electric grid.

Technological integration

The building is constructed with a concrete façade on which the PV modules were installed with a mounting system from the German company U-kon. Metal hooks were fastened with rivets to the module frame and the module was than hang onto vertical bars attached to the building structure.

23-06. (3) Final installation. It is not obvious to everyone that the black façade is BIPV.

23-07. The installation was made with a scissor lift.

23-08. PV modules start above ground floor level.

Installer

Lars Hedström at Solkompaniet was hired as a consultant and investigated the design of the facade together with the architect and Uppsalahem.

Architect

The architect Mats Egelius was a key person in the process. He was the person who introduced the idea of a PV façade. He was hired as a city planner already when the restructuring of the neighborhood next to the train station was planned. It would be a new entrance to the city and the current building would be a symbol of innovation and sustainability. When black modules were suggested instead of blue, it was said that a building permit was not going to be allowed for a black façade. However, Mats had a large mock-up built and prepared detailed written material, much more accessible than normal, since he and Uppsalahem wanted this to be built. In the discussions with the Uppsala municipality about the building permit, Mats also borrowed a black module to demonstrate it. He managed to convince the officials to give a permit for the black façade.

Finance

Of the 350.000 Euro total investment, the share for the PV contractor part was 280.000 Euro and the rest was for sheet metalwork, connections and internal costs. The PV module share of the PV contractor cost was 32%. The installation work represented a large share of the cost, since it was more complex than a standard installation on a roof. In the first investment decision, the PV façade was not included. It was added in an extra decision, in a meeting regarding the building permit and budget in 2010. Until then, an alternative glass façade had been discussed. An investment subsidy of 120.000 Euro was granted for the PV installation. However, this was not vital for the decision to install PV, since the decision was taken before the subsidy was granted and the subsidy was considered as a bonus. If a glass façade had been chosen instead, the façade cost had been about 250.000 – 300.000 Euro, similar to the PV façade cost. Taking the investment subsidy into account, the cost for the PV façade became lower than for a glass façade. In addition, it is believed that the PV installation increases the value of the building.

Additional income is obtained from electricity certificates, with a value of 0,01 €/kWh early in 2018, and from tax deductions for excess electricity fed into the grid, maximized to 1800 Euro/year per company. The tax deduction was introduced in 2015 and had no influence on the investment decision.

Lessons learned

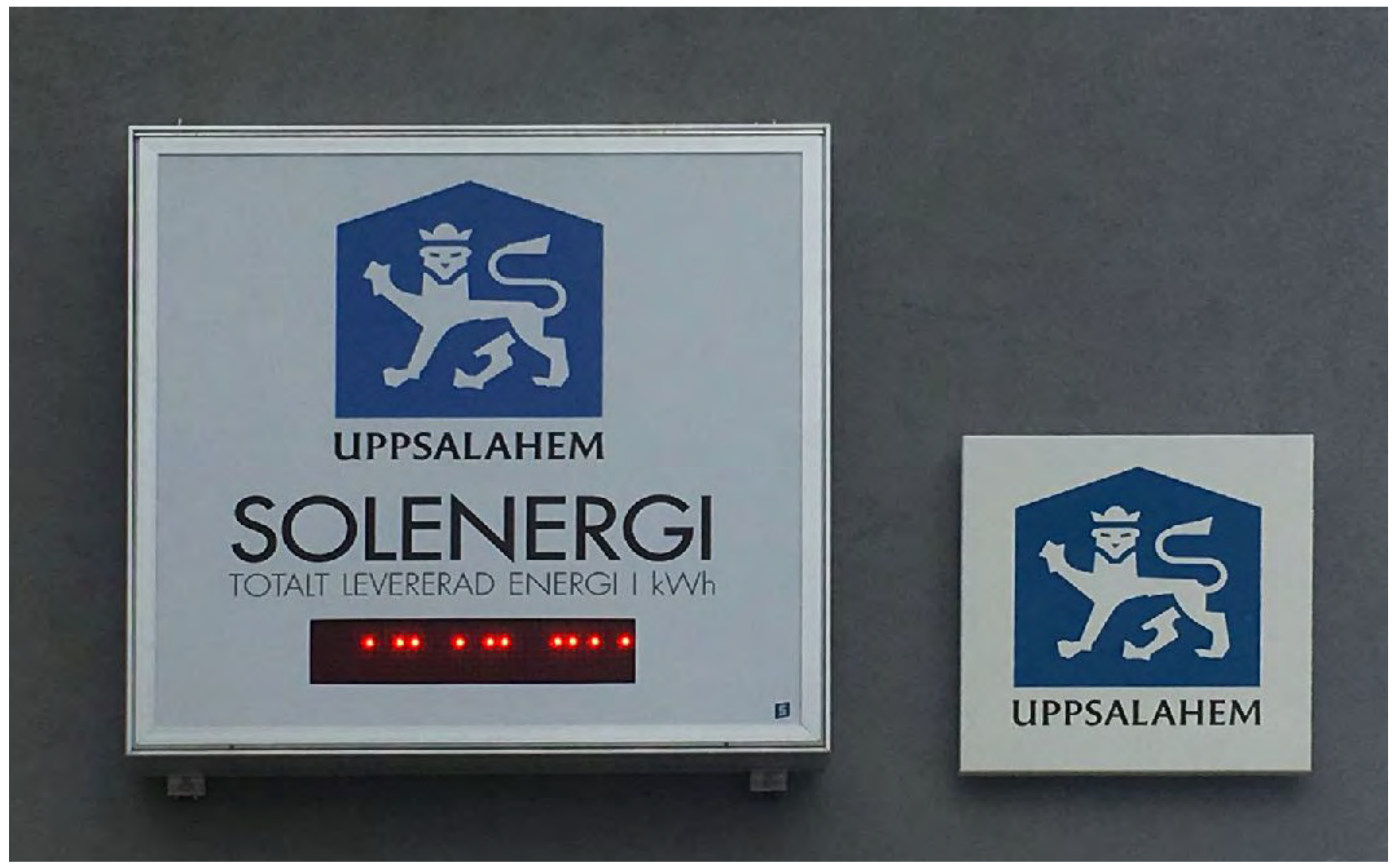
One crucial success factor was that BIPV was included very early in the process and integrated into the design. The total building process was very long, starting in 2006 when the architect suggested the use of BIPV, the building was finalized in 2014. It would have been much more difficult to include BIPV if the idea had come at a later stage.

The PR value became higher than expected, including media attention, visits by politicians, and other study visits at both national and international levels.

The curved façade in Frodeparken made the installation more difficult than if the façade had been a straight façade.

The building owner Uppsalahem is very pleased with the BIPV façade. Even though Uppsalahem has not made a similar façade installation since this one, they now consider PV on roofs in every project and plan buildings to accommodate PV installations on roofs in the future. For instance, they plan the position of other installations on the roof such that they would not prevent PV installations from being added in the future.

Exchange rate 10 SEK/Euro used.



23-09. Display on the façade.

MFH Renovation Hofwiesenstraße, Zürich (CH)

Project data			
Project type	Renovation		
Building function	Residential building - Apartments		
Integration system	Ventilated opaque façade		
Location	Hofwieserstraße 22, 8057 Zürich		
Architect	Viridén+Partner AG	Year	2016
BIPV system data		**Producer data**	
PV modules	Customized frameless modules on façades	Producer	PVP Photovoltaik GmbH (Kioto Solar)
Solar technology	Monocrystalline silicon	Address	Wernersdorf 111, 8551 Wies (AT)
Nominal power	159 kWp	web	www.kiotosolar.com
System size	1586 m^2		
Module size	1545 modules in 18 different sizes		
Orientation	North, east, south, west		
Tilt	90°	Author/editor	Pierluigi Bonomo

MFH Renovation Hofwiesenstraße, Zürich (CH)

24-01. BIPV façade.

24-02. Architect Karl Viridén.

Interview with Mr. Karl Viridén (Architect and President of Viridén+Partners AG)

What were your first projects with BIPV?
Mr. Viridén: Our first experience with solar systems was with a historical building (1896) in Basel that was renovated in 2009. It is important to highlight that the first goal of renovation projects is to try to reduce energy consumption as much as possible and, then, to design solar systems such as BIPV to provide renewable energy.
The same approach was adopted for the renovation of the Multi-Family House (MFH) in Romanshorn (CH). In this project, the building's volume was increased, the envelope was insulated well and conventional PV modules were used to realize a BIPV façade. This was a very challenging renovation because, on the one hand, the modules' size was standard and, on the other hand, the façade's dimensions change from one floor to the next. A BIPV façade has been realized also for an administrative building in Flums (CH) using the same approach and with standard PV modules. This experience has allowed us to learn a lot from issues encountered and, especially, from thorough investigation of PV technology and its applications into the building's envelope. Indeed, if I should give a suggestion to architects who have never had experience with BIPV, it is to start from the basics!

What have been the special features of the MFH Hofwiesen-/Rothstrasse project?
Mr. Viridén: In this renovation project, we set up a new kind of contract between the building's owner and the Ecorenova, the company that is responsible for the BIPV façades and the solar systems on the roof. Moreover, we have been able to transform an existing building into a Plus-Energy Building that is different to the previous ones, thanks to its coloured skin that makes the PV cells invisible. In order to collect feedback on this architectural design, we showed the picture of this building to an audience and we asked them whether the building of the future could look like this. Surprisingly, only 5% provide negative feedback, while 77% answered that this could be the appearance of future buildings, both for aesthetic and ecological reasons, and 18% declared that more electricity is better than a nice façade because of the eco-funding subsidies.

Decision-making and Process

In 2010, the private owner of the building asked for a renovation in order to transform the existing low energy performance building into a Plus-Energy Building, as well as to add eight flats. In addition to this, also the architectural language of the renovated building was a criterium for the project. As a proposal, Viridén+Parterns designed the energy renovation of the building, together with thermal insulation of the building façades and the realization of aesthetically appealing BIPV façades.
Moreover, in order to realize an innovative BIPV façade solution, the Ecorenova partner took the risks (and the benefits) to maintain the façades and the roof by means of a contract with the owner. In this way, new ideas have been developed by Ecorenova, which had the chance to investigate different BIPV module possibilities. Indeed, parallel to the construction work, research on the ideal BIPV modules has been carried out. Several coloured BIPV modules have been evaluated both in terms of energy output and aesthetic appearance, with the final aim to conceal the PV cells.

When the optimal prototype had been found, about 40 modules (electrically active and dummies) were produced and several architects were called to recognize the material of the modules. When the majority of them did not identify the real material, the architects realized that they had reached their goal.
In addition to this, it is important to highlight that the Swiss Federal Office of Energy supported the conversion of the Hofwiesen-/Rothstrasse multi-family house as a lighthouse project, as a proof that a Plus-Energy Building is possible by a comprehensive refurbishment concept with an optimal and innovative building envelope.
Moreover, during our experiences with BIPV façades, it became evident that the installation process involves several actors at the same time, in contrast to a traditional façade where there is one company responsible for plastering. In this case, instead of only the plasterers, there are both the electrical company for connecting the PV modules connections and the company for the façade installation, together with the architect and the site manager. Hence, there some small details that have to be taken into account also during the process.

24-03. Building before renovation.

24-04. New BIPV look of the building.

Building / system integration

Formal integration

The feature of this BIPV project is the invisibility of the PV cells thanks to a special glass treatment that allows them to disappear behind a green-grey front glass cover. Since the building's geometry is complex, 13 different formats of coloured BIPV modules and 5 formats of dummy modules were developed to obtain an homogenous and uniform appearance. The smallest BIPV module has an area of 0.4 m^2 wide and the largest module is 1.6 m^2 large. However, the production capacity depends on the number of PV cells that are installed behind the coloured front glass cover of the module. Indeed, where the installation of PV cells is not worthwhile (2% of the whole façades' surface), coloured dummy modules have been used.

Energy integration

The energy yield of the façade BIPV system and the roof PV system has been monitored since November 2016.
The façade's modules are connected in strings of a minimum of 2 to a maximum of 5 modules, because of the shadows caused by the complex geometry of the building.

From the available data, so far, it has been determined that all the BIPV façades contribute by a significant amount to the total energy yield. Furthermore, the distribution of BIPV modules over the different orientations results in power generation throughout the entire day.

Technological integration

The façade BIPV modules are laminated safety glass elements that have been used as the cladding of a rear-ventilated façades. However, not only an air cavity and thermal insulation are hidden behind the modules. Indeed, there are several yield optimizers that can be easily checked thanks to the easy dismantling mechanism of each module that is combined with metal back rails that are attached adhesively to the modules.
In addition to this, the presence of the adhesive of the backrails allows better absorption of the horizontal load than with fixed point connections. Moreover, it is should be emphasised that, in order to prevent a thermal bridge between the outer façade and the inner envelope, the backrails and other parts of the substructure are made of chrome steel or other materials with low thermal conductivity.

24-05. BIPV module prototypes.

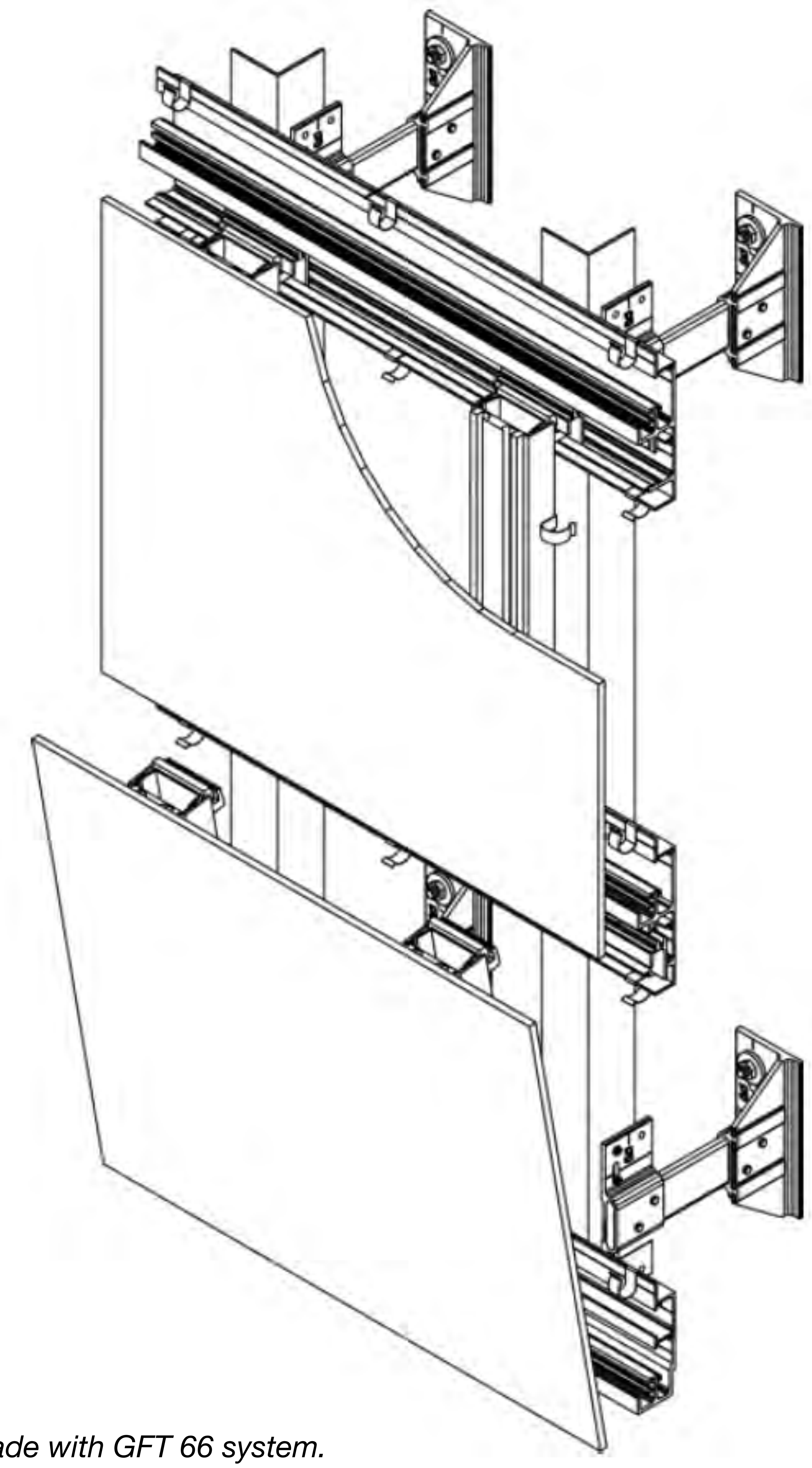
24-06. New BIPV appearance of the building.

Façade owner
Thanks to a specific contract with the building owner, EcoRenova AG represents the BIPV façade owner.

Façade manufacturer
For the ventilated façade construction, the substructure system was developed by Gasser Fassadentechnik specifically for glass and photovoltaic façades. In particular, the substructure system allows to install each PV module to be installed and replaced individually.
www.gft-fassaden.swiss

BIPV Module Producers
The façade BIPV modules were manufactured by PVP Photovoltaik GmbH in Wies (Austria).
www.pvp.co.at

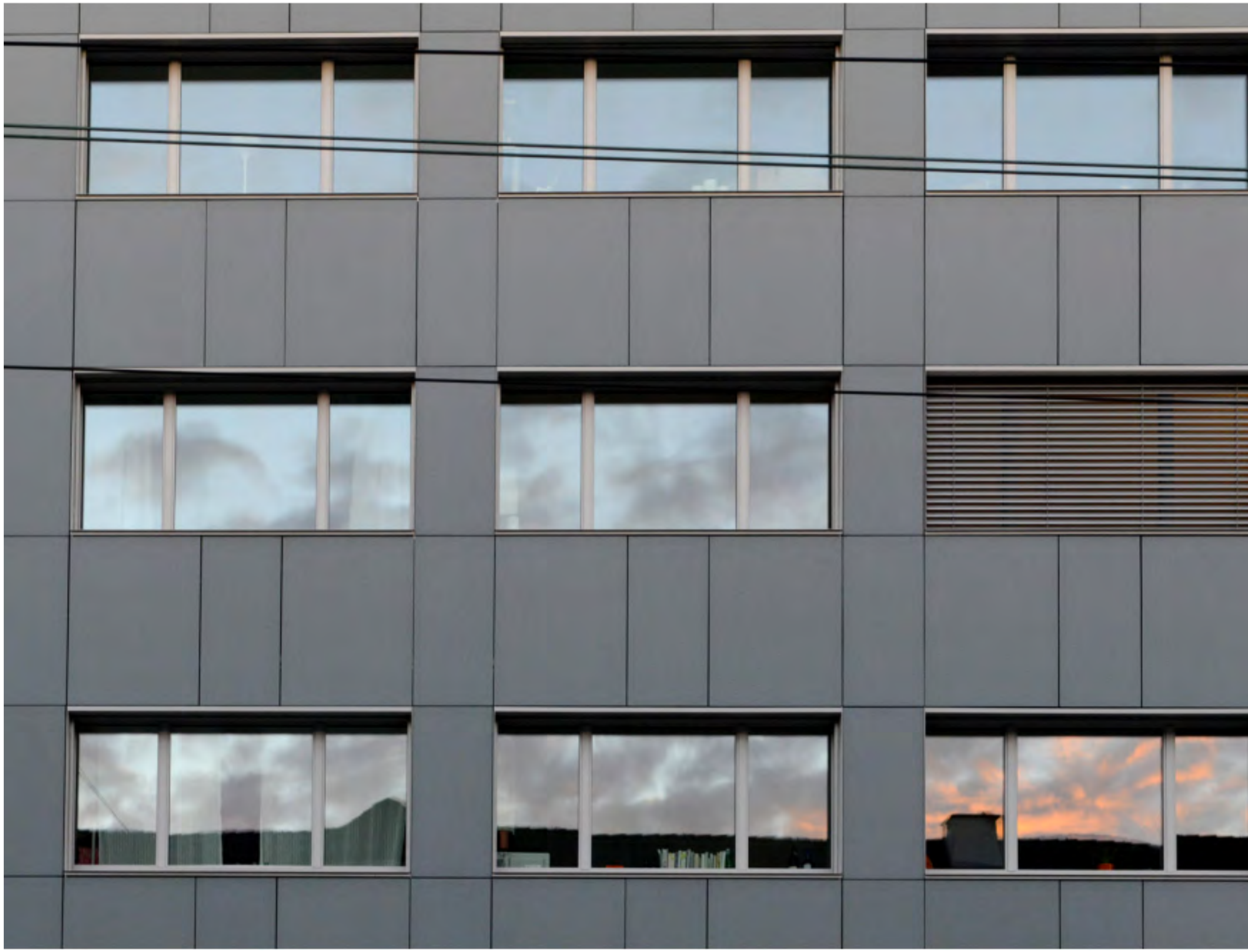
Façade Installer
The BIPV façade was installed by Diethelm Fassadenbau AG.
www.diethelm-ag.ch


24-07. Detail of the BIPV façade with GFT 66 system.

24-08. North façade.

Finance
For the planning, delivery and installation of an active BIPV glass façade, a difference of 300 - 400 Chf/m² is expected compared to a normal glass or high-quality ventilated façade cladding. However, this difference will be amortized in around 15 to 20 years by selling the electricity generated.

Lessons learned
The experience of the realizing the BIPV façades demonstrated that the process involves several actors at the same time.
In detail, this has lead to learning how to manage and the coordinate several different actors during the building process, in contrast to a traditional process for "passive" façades.



24-09. Detailed view of the west façade.

Renovation ‘Schnitterhaus’, Nechlin (DE)

Project data			
Project type	Renovation		
Building function	Residential		
Integration system	Shading louvres, window shutters, roofing		
Location	17337 Nechlin		
Architect	Krekow planungsgesellschaft mbH	Year	2015
BIPV system data		**Producer data**	
PV modules	Custom-made	Producer	Solar Nova GmbH, Wedel, Germany
Solar technology	Monocrystalline silicon, glass-glass modules	Address	Wernersdorf 111, 8551 Wies (AT)
Nominal power	Shutters 1160 Wp	web	www.solarnova.de / www.astrid-schneider.de
System size	Shutters: 8 modules / Shading : 8 modules		
Module size	1035 x 710 mm^2, 1035 / 2445 x 710 mm^2	Solar Façades	Astrid Schneider, Solar Architecture Berlin
Orientation	Southwest		
Tilt	Shutters 90°	Author/editor	Astrid Schneider

Renovation ‘Schnitterhaus’, Nechlin (DE)

25-01. BIPV shutters.

Interview with the clients Ute and Jörg Müller

Challenges

The energy-related renovation of the farmstead previously called 'Schnitterkaserne' was part of our effort to modernize important buildings in the centre of the village 'Nechlin' in Brandenburg. This part of the countryside close to the Polish border, about 120 km north-east of Berlin, is quite isolated; young people and businesses have moved to the cities and are abandoning the villages. Thus, we had the option either to modernize or to watch the buildings fall apart. This building had not been renovated for decades and the building substance and technology were in a very poor state. From an economic viewpoint it was a difficult decision, whether to renovate or to demolish the building. However our intention was to save the historic substance and spirit as it is an important part of the village centre.
Our idea was to apply our vision of 100% renewable energy supply to give new impulses to the historic village. As we had already started to build up a local heating network based on biomass and solar thermal energy it was clear, that the main tasks in the renovation of the former 'Schnitterkaserne', which is connected to this 100% renewable heat supply, were to improve the energy efficiency to the maximum and to use all suitable roof and façade areas to integrate PV modules to generate solar electricity.

Aesthetics and functionality

From the point of view of aesthetics as well as ecology it was clear for us, that we prefer the integration of the PV modules into the building surfaces which needed to be renewed anyhow. What we especially like is the functional PV roofing and the integration of modern solar technology with historic heritage building-elements such as window shutters. At the same time the shading function of the Solar Window Shutters and the shading louvres is very important for the comfort of the inhabitants in the summer time.

After winning a prize for sustainable construction in heritage buildings and the 'Energy Efficiency Prize' of the state of Brandenburg the former granary and the dwelling, which has now been renamed 'Schnitterhaus' are an important part to creating a new image of the modern, solar powered village Nechlin village – a 'village full of energy' as we like to say. Nechlin – a 'village full of energy' as we like to say.

25-02. Ute and Jörg Müller

Decision-making
The client was very interested in integrating PV electricity generation into the buildings renovation and was a driving force. However there was a permanent conflict between realizing the most advanced and beautiful BIPV elements and the cost argument. Decisions about product and supplier choices were made by the architect together with the clients.

Process
The process of designing individually BIPV elements, which are multifunctional involves many stakeholders. Regarding the façade, there was no 'ready-made' system available. Several companies had to be involved: steel substructure manufacturers, carpenters to produce the wooden frames, a PV module manufacturer, advanced installers and a solar electrician.


25-03. BIPV shutters closed.


25-04. BIPV shutters in ventilation mode.

Building / system integration

Formal Integration
A feature of this BIPV project is the invisibility of the PV cells thanks to a specific glass treatment that allows them to disappear behind a green-grey front glass cover. Since the building's geometrical configuration is complex, to obtain an homogenous and uniform appearance, 13 different formats of coloured BIPV modules and 5 formats of dummy modules were developed to obtain a homogeneous and uniform appearance. The smallest BIPV module has an area of 0.4 m^2 and the largest module has an area 1.6 m^2. However, the electricity generating capacity depends on the number of PV cells that are installed behind the coloured front glass cover of the module. Indeed, when the installation of PV cells is not economically viable (2% of the whole façades' surface), coloured dummy modules have been used instead.

Energy Integration
The electricity yield of the façade BIPV system and the roof PV system has been monitored since November 2016.
The façade modules are connected in strings of a minimum of 2 to a maximum of 5 modules, because of the shadows caused by the complex geometry of the building. From the available data, so far, it has been determined that all the BIPV façades contribute in a significantly to the total electricity yield. Furthermore, the distribution of BIPV modules over the different orientations distributes the power generation throughout the entire day.

Technological Integration
The solar window shutters are made of glass-glass modules with crystalline silicon solar cells, which are 'conventionally' integrated into wooden frames. These shutter elements are attached and made movable with a very sophisticated mechanism, which allows the shutter to remain parallel to the wall while it was moved by supporting arms. This means that the solar active surface is always directed towards the sun, independently of whether the shutter is opened or closed.

To enable installation, wooden frames were attached to the pre-installed stainless steel fixtures on the massive wall. The three cm thick planks form a reveal around the windows opening. This was very important to provide a stable and exactly defined substructure for the window shutters, as the 25 cm thick insulation turned out to be a constructive obstacle – and the façade of the historic building was certainly not planar. As a result, the original wall and the final surface of the insulation were not parallel. Furthermore, moving shutters would in time destroy the weak surface of a compound insulation panel. As a solution, the wooden framing for the window's reveal was designed and attached to the original metal elements anchored in the massive wall to be an accurate and stable backbone and counterpart for the solar window shutters. This wooden structure allowed optimal integration.

The metal substructure moving the solar window shutters in a semicircle were detailed and designed by the solar architect and then manufactured by a metal-working company from Saxony. The electric cables are hidden inside the upper metal arm and connected to the cables, which were already put in place during the construction works.

25-05. Street view.

25-06. BIPV shutters in ventilation mode.

Multfunctionality

In summer, when it is very hot and shading is needed, the shutters could stay closed all day, while in winter, every sun ray could be enjoyed by opening the shutters wide during the day.

As a highlight there is another feature: to allow shading and ventilation at the same time, a so-called ‘ventilation position’ was designed: the lever used to close the window shutter from the inside was specially designed to allow a semi-closed position. In this position the window shutter is nearly closed but due to the movement path’ is about 15 cm in front of and parallel to the wall. This allows a chimney effect with a comfortable ventilation behind the solar shutters, while the window opening and thus also the room are still fully shaded. This provides a double cooling effect and is often used in summer by the inhabitants. Especially for the rooms on the ground floor, the protective function providing more privacy is a welcome effect of the solar window shutters.

Solar Architect : Astrid Schneider:

Aesthetics

In this case, the integration of the PV elements into the architecture is not so much a matter o colour, but concerns the structure, function, materials and appropriate sizes. The PV elements are structurally integrated as roof elements, shading louvres and shutters - as functional construction elements which fit into the buildings relief and texture. However, the colours of the façade, wooden frames and metal elements are composed to create an overall aesthetically and harmonious effect. The historic architecture is enhanced by the use of solar technology.

Local heritage

The big challenge was to find an architectural expression which would suit the historic building and village on the one hand, but on the other hand would be modern and simple. Window shutters were historically not represented on this building but several examples were found in neighbouring villages. Other former farm houses or village buildings also had comparable architectural elements like wooden framing for the window’s reveal and ‘stucco elements’ made of wood above them. Furthermore the famous Berlin architect Schinkel use wooden reveals and window shutters for the castles in Berlin and Potsdam he was designing, even when these buildings had very stable brick walls. However, the integration of colour and exact shape also seemed to be easier for him with the interesting detail of a wooden frame around the windows opening. His work was a great inspiration for the classic design of the shutters and the framing.

Thus, the solar window shutter elements were in this sense integrated into the local architectural heritage of Berlin and Brandenburg. The little wooden ‘stucco’-elements above the window somehow give the window opening an ‘eye’. The same effect occurs with the PV shading elements above the other windows: they give the windows more ‘esprit’. The levering elements at the same time make the windows and the façade more durable by protecting them from rain. Furthermore the shading effects are enhancing not only the indoor comfort but also the structure of the façade.

25-07. Astrid Schneider.

25-08. BIPV shutters.

Finance

The building-integrated PV modules of the 'Schnitterhaus' were financed with the feed-in tariff according to the 'EEG – Erneuerbare-Energien-Gesetz', the German 'Renewable Energy Law'. All electricity produced is fed into the public grid and is remunerated by the grid operator. This could make the roof-integrated power plants economic within about 15 years. The façade integration with the shading elements above the windows and the solar window shutters are valued due to greater comfort in summer, as well as their contribution to the aesthetic appearance of the building. The value is an interestingly sculptured façade and a comfortable building.

Lessons learned

To find an optimal position for the inverters was difficult, as the building has no cellar and there was no special room available for technological equipment. To be allowed to install the inverters in the staircase, they would have had to fulfil the required fire rating for the staircase as an escape route. Otherwise, a 90-minutes fire-resistant box would have had to be built. However, as inverters produce heat, this task would have had very expensive, as a special construction would have been needed to ensure ventilation. Finally, it was the wish of the client that all inverters be installed in the neighbouring building to allow an even simpler electrical connection with the grid and to establish an island network if needed.

After the inverters had been installed in an upper storey of the neighbouring granary, it turned out, that the smallest inverter constantly emits a rattling noise. At the position of installation, this is not a problem, but it really would have been, when it would have been if the inverter had been placed within or near a room that was in daily use.

It is strongly recommended to test inverters not only for fire safety but also for noise emissions to make them ideally suitable for construction purposes. At least some information about these properties would be helpful for planning purposes.

25-09. BIPV shutters.

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3-03. Red coloured elements were added by the architect to break up the black façade.	© Undervisningsbygg Oslo KF
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5-10. Umwelt Arena during construction (the building site itself was CO2 neutral).	© René Schmid Architekten AG
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10-03. View from the outside. BIPV modules were installed with a small slope to facilitate water drainage.	© ONYX
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14-02. Mrs. Luo, chief architect.	
14-03. PV roof for shading the roof garden.	
14-04. Façade of the building.	
14-05. Southwest view of the building.	
14-06. Roof structure from the inside.	
14-07. BIPV canopy.	

14-08. Aerial view of the main building.	
14-09. Artist's impression of the BIPV parapet elements.	
14-10. Mrs. Mao, installer	
14-11. BIPV façade.	
14-12. Artist's impression of the main building.	
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20-07. BIPV system as the central component of the main building façade.	© EURAC
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22-02. The Skanska project manager, Mr Roald Rasmussen.	Åse Marie Landsverk, Husbanken
22-03. Building site after BIPV installation.	Inger Andresen, ZEB Sintef/NTNU
22-04. Mounting of the BIPV modules.	© Skanska
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22-15. Skarpnes residential building.	Jarle Kavli Jørgensen
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23-04. The evolvement of the BIPV façade of Frodeparken. (1) Original design in building permit.	© White arkitekter
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23-06. (3) Final installation. It is not obvious to everyone that the black façade is BIPV.	© BEAR-iD
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23-08. PV modules start above ground floor level.	© White arkitekter
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Colophon

IEA-PVPS TCP Task 15 “Acceleration of BIPV”

Case study book (Subtask A) 2017-2019

Subtask leader: Tjerk Reijenga, BEAR-iD (NL)

Editorial board: Tjerk Reijenga, BEAR-iD (NL)
Michiel Ritzen, ZUYD (NL)
Alessandra Scognamiglio, ENEA (IT)
Karin Kappel, Solar City (DK)
Francesco Frontini, SUPSI (CH)

Proof-reading: Helen Rose Wilson, Fraunhofer ISE Freiburg

Contributors: Austria - Dieter Moor, ertex solar; Astrid Schneider, AIT; Peter Illich - Technikum Vienna
Canada - Véronique Delisle, Konstantinos Kapsis, Natural Resources Canada
China - Limin LIU, Beijing CORONA Science & Technology
Denmark - Karin Kappel, Solar City Denmark
Germany - Astrid Schneider, Solar Architecture
Italy - Laura Maturi, Jennifer Adami, EURAC; Alessandra Scognamiglio, ENEA
Japan - Hisashi Ishii, LIXIL
The Netherlands - John van Oorschot, Michiel Ritzen, ZUYD
Norway - Anna Gerd Imenes, TEKNOVA
Spain - Nuria Martin, CIEMAT
Sweden - Bengt Stridh, Mälardalen University; Rickard Nygren, White arkitekter; David Larsson, Solkompaniet
Switzerland - Francesco Frontini, Pierluigi Bonomo, Erika Saretta, SUPSI

ISBN 978-3-906042-92-3

V.15 - November 2020