IEA PVPS TASK15:
ENABLING FRAMEWORK FOR THE ACCELERATION OF BIPV - FASE 2
2020-2023

Final report

December 2023

Title:
IEA PVPS task15: Enabling Framework for the Acceleration of BIPV & Fase 2, 2020-2023

EUDP Project number
134-22006

Project Partners
DTU Electro (project coordinator)

Written by:
Peter Behrensdorff Poulsen, DTU Electro (Project manager)
Sune Thorsteinsson, DTU Electro
Markus Babin, DTU Electro

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Front page
Photo from Task 15 meeting San Sebastian, 4th October 2022.

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1. Project details

Project title	IEA PVPS task15: Enabling Framework for the Acceleration of BIPV & Fase 2, 2020-2023
File no.	134-22006
Name of the funding scheme	EUDP
Project managing company / institution	DTU Electro
CVR number (central business register)	30060946
Project partners	
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2. Summary

2.1 English summary

The project, led by DTU Electro focused on Denmark's involvement in the IEA PVPS Task 15, centering on Building Integrated Photovoltaics (BIPV). The project was structured into three main work packages: project management, task participation, and dissemination.

Task Participation: DTU Electro made substantial technical contributions, particularly to Subtask B and E. In Subtask B, the team developed an evaluation matrix for BIPV installations, integrating aspects like glare, color perception, and architectural goals. In Subtask E, DTU Electro contributed to the analysis of BIPV operating temperatures and the performance modeling of BIPV systems. These contributions were essential in standardizing practices and updating temperature models for BIPV systems.

Dissemination: The project's findings were shared through seminars, the IEA PVPS website, social media, and conferences like EUPVSEC. The results have been instrumental for building planners, architects, city planners, and BIPV manufacturers, providing them with tools and methodologies for better BIPV project implementation.

The project aligned well with its original objectives, successfully enhancing public access to technical BIPV information and contributing to the standardization in the BIPV sector. The collaborative efforts led to the development of systematic methods for assessing BIPV installations, influencing both Danish stakeholders and the international BIPV community. The project's results are expected to play a significant role in the future development of BIPV solutions, particularly in light of the EU's push for solar-ready buildings by 2030.

2.2 Danish summary

Projektet, ledet af DTU Electro (tidligere DTU Fotonik), fokuserede på Danmarks deltagelse i IEA PVPS Opgave 15, som centrerer omkring Bygningsintegreret Fotovoltaik (BIPV). Projektet var struktureret i tre hovedarbejdspakker: projektledelse, opgavedeltagelse og formidling.

Taskdeltagelse: DTU Electro bidrog betydeligt på det tekniske plan, især til Underopgave B og E. I Underopgave B udviklede teamet en evalueringsmatrix for BIPV-installationer, som integrerede aspekter som blænding, farveopfattelse og arkitektoniske mål. I Underopgave E bidrog DTU Electro til analysen af driftstemperaturer for BIPV og præstationsmodellering af BIPV-systemer. Disse bidrag var essentielle i standardiseringen af praksis og opdateringen af temperaturmodeller for BIPV-systemer.

Formidling: Projektets resultater blev delt gennem seminarer, IEA PVPS-webstedet, sociale medier og konferencer som EUPVSEC. Resultaterne har været afgørende for bygningsplanlæggere, arkitekter, byplanlæggere og BIPV-producenter, og har forsynet dem med værktøjer og metoder til implementering af BIPV-projekter.

Projektet var godt afstemt med sine oprindelige mål, og det lykkedes at forbedre offentlig adgang til teknisk information om BIPV og bidrage til standardiseringen i BIPV-sektoren. Samarbejdsindsatsen førte til udviklingen af systematiske metoder til vurdering af BIPV-installationer, hvilket påvirker både danske interessenter og det internationale BIPV-fællesskab. Projektets resultater forventes at spille en væsentlig rolle i fremtidig udvikling af BIPV-løsninger, især i lyset af EU's skub for solklare bygninger inden 2030.

3. Project objectives

The project was focussing on enhancing the Danish participation in IEA PVPS Task 15 "Enabling Framework for the Acceleration of BIPV" phase 2, particular in

- **Subtask B Cross-sectional analysis: learning from existing BIPV installations and subtask**
- **SubTask E Pre-normative international research on BIPV characterization methods**,

ensuring the more technical knowledge from this international group of experts is brought to the Danish BIPV industry but also contributing as experts to establish and share knowledge from our research and test systems particular within color perception and field tests of BIPV system in Nordic climates.

The technology in focus within this task is building integrated photovoltaics, where the solar photovolta-ic pan-els has a dual functionality as a construction product, but also as an energy generator. Photovoltaic systems on buildings, especially daytime use buildings with synchronous power production and consumptions enables local production of electricity, using already occupied areas, reducing the need for grid expansions, and in the case of BIPV it also saves conventional building materials reducing the total environmental impact in the society.

Task meeting in Adelaide - Australia

4. Project implementation

The project was meticulously structured into three distinct work packages, ensuring a focused and effective approach.

1. Project Management: Under the leadership of Peter Poulsen, the project management team adeptly coordinated the various activities, maintaining a steady progress towards our goals.

2. Task Participation: DTU Electro's technical contributions, particularly in Subtask B, were significant. The team, drawing from extensive research in glare and color perception, developed the visual aspect of the multi-functional comparison matrix for Building Integrated Photovoltaics (BIPV) installations. This visual evaluation, initially subjective, was enhanced by our proposed evaluation methodology, which injected a significant degree of objectivity. This new method was put to the test during a Task meeting in Stockholm, leading to the identification and subsequent adaptation to certain challenges. In Subtask E, DTU Electro's test installation for BIPV, along with five other installations, played a crucial role in quantifying the maximum operating temperature of BIPV modules. This collaboration also improved the modelling accuracy of standard PV energy forecasting programs for BIPV systems. DTU Electro maintained an active presence in all plenary task meetings held biannually in various international locations (Vienna, San Sebastian, Stockholm and Adelaide), contributing significantly to online work group and task meetings. The team is currently involved in finalizing an IEA report and has been instrumental in designing the work plan for phase 3 of the project, leading several activities.

3. Dissemination: The dissemination of our findings to the Danish industry and BIPV community has been a resounding success. Through annual seminars, we have engaged a keen audience, highlighting the project's achievements. Additionally, our reports and findings have been published on the IEA PVPS website, shared across social media platforms, and certain key results were presented at the European Solar Conference (EUPVSEC).

The project unfolded largely as anticipated, with only minor deviations. While there were minor delays in IEA PVPS publications due to more complex data analysis than initially expected, these were swiftly addressed. To align more closely with the full duration of the phase 2 IEA PVPS task 15, we extended the project timeline. Throughout this journey, we encountered no unexpected problems, a testament to the thorough planning and adaptability of our team.

5. Project results

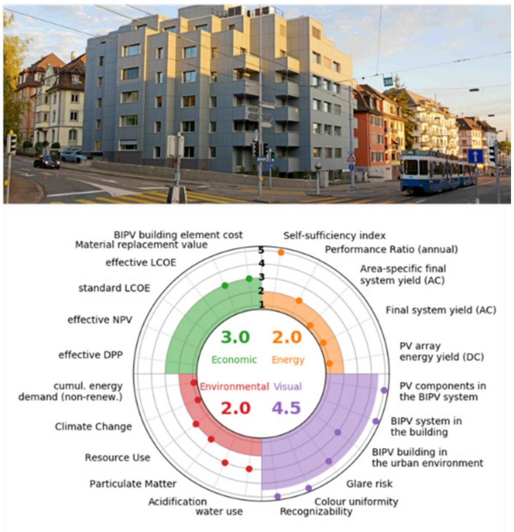
The project successfully achieved its primary goal of collecting and unifying international research and development in the field of Building Integrated Photovoltaics (BIPV), as outlined in the objectives of the IEA PVPS task 15.

5.1 Technological Achievements:

DTU Electro's involvement primarily focused on Subtasks B and E, contributing significantly to each:

Subtask B - Cross-sectional Analysis: This task aimed at providing architects, planners, and building designers with a multidisciplinary performance evaluation tool for BIPV installations. DTU Electro played a critical role in identifying measurable variables and parameters that encapsulate the performance of BIPV systems. This comprehensive assessment, covering energy, economic, ecological, and aesthetic aspects, facilitated the comparison of different potential BIPV projects. Notably, DTU Electro developed criteria for assessing the visual appearance of BIPV installations, taking into account factors like local environment and glare, and evaluating how these installations meet architectural goals.

Hofwiesenstrasse, Zürich: Karl Viriden



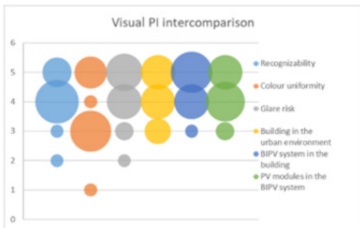
Colour uniformity

Property	Points
Base rating	3
Hue and/or saturation change within single module/element	-1
Hue change between single modules/elements	-1
Saturation/lightness change over entire façade	-1
Colour-matched to surrounding materials (or no others)	+1
Homogeneous colour over entire façade	+1
Final rating:	1-5

Glare risk

Property	Points
Base rating	3
Satinated or highly structured glass (no specular reflections visible)	+1
Flat glass (specular reflections highly visible)	-1
Facing only low traffic areas	+1
Facing high traffic areas	-1
Small, unconnected areas (module areas < 2m² AND < 25% coverage)	+1
Final rating:	1-5

Comfort Hotel Solna, Stockholm: White Arkitekter



Subtask E-5 Electricity Yield: DTU Electro's BIPV field test was one of six installations that contributed to the evaluation of BIPV operating temperatures and the performance modelling accuracy of the System Advisor Model. The findings, particularly regarding operating temperature extremes, have informed updates to industry standard practices and model coefficients. Additionally, the project evaluated the electricity yield of various BIPV installations, confirming that the System Advisor Model accurately predicts the performance of uncolored BIPV systems.

For the operating temperature modelling the extreme temperature analysis has been in focus. The standard practice in the industry is assuming that BIPV always is operating with a temperature profile corresponding to no rear ventilation and frequently reaches temperature above 70 degrees, in which case higher restrictions for the materials and installations is demanded via the relevant interna-tional standards. The temperature analysis from these 6 cased though revealed, that the existing temperature prediction model works sufficiently well, however model coefficients require updates, and the logical chioce of model coefficients is not always the most accurate, in order to determine the operating temperatures 2 % high extreme temperatures and that temperatures above 70 degrees only occurs for the complete insulated back modules, installed at DTU. The 6 cases internationally are shown below (DTU represent 2 cases).

DTU (DK) – BIPV Façade

Fraunhofer ISE (DE)
BIPV Façade

Mittag et al (2016) TPedge: glass-glass photovoltaic module for BiPV-applications

CIEMAT (ES) – BIPV Façade

© CIEMAT (Juan Carlos Gutierrez)

Varennes Library (CA) – BIPV Roof

© Maxime Gagné

BEST Lab (CN) – BIPV Windows

Case study	Country	Best fitting coef.	Monitored	Insulated-back coef.	Logical coef.
Varennes Library (ventilated roof)	Canada	64.4	63.8	**88.3**	58.6
CIEMAT (façade)	Spain	46.2	60.9	50.4	37.5
Best Lab (windows)	China	53.1	51.6	**71.9**	69.7
DTU Risø (close mount façade)	Denmark	55.0	58.3	55.0	55.0
DTU Risø (insulated back façade)	Denmark	**70.9**	**71.4**	**70.9**	**70.9**
Fraunhofer ISE (façade)	Germany	67.1	62.6	**74.2**	53.5

Further the accuracy of the electricity yield has been evaluated on the Varennes library, the CIEMAT façade and on the DTU curtain walls. Detailed evaluation of the results is under completion, however the temperature models used, seems to be the largest contributor to uncertainty, and the overall conclusion is that System advisor model can predict the performance of (uncolored) BIPV systems reasonably well.

Target Group and Added Value:

The multidimensional evaluation matrix is targeting building planners, architects and city planners. They are now equipped with an evaluation tool, where they can assess future BIPV projects based on objec-tive criteria, and this will help planners to identity potential risks (e.g. glare) and improve the quality of BIPV projects. As such this matrix taps into the construction industry and is yet another important step on the way to learn the construction sector to use, handle and appreciate BIPV as a construction prod-uct. In the future BIPV is expected to significantly increase its market share especially in EU supported by the newly negotiated EPBD directive, demanding all buildings to be solar ready by 2030.

For the subtask E results, the maximum temperature analysis results have been included in a proposal for an updated standard, and the results for the extreme temperature analysis, showing that higher tem-peratures than 70 degrees is more the rare case rather than the common case for BIPV, increases the material selection for BIPV manufactures and the selection of BIPV supporting structures, and the ener-gy yield simulation assessment provides confidence in existing simulation programs.

Dissemination Efforts:

The project results were disseminated through various platforms and events, targeting both international and Danish stakeholders:

International Dissemination:

- Early results were shared at a DTU Summer School in August 2022.
- Findings were presented at the Building Green November 2022 event and a collaborative seminar with Rockwool in December 2022.
- A final seminar on December 14, 2023, highlighted the outcomes of Task 15, with a focus on DTU Electro's contributions, attracting significant industry interest. Videos from the presentation from the event can be found here: https://www.youtube.com/playlist?list=PLva_rYq-UqP_cgkXujGOuQ3VLtZ09mozH. Photo from a tour is shown below and on page 11 is a photo from the lecture room.

Publications and Online Presence:

- The work was showcased at Task 15 plenary meetings and the EUPVSEC 2023 conference. (https://user-area.eupvsec.org/proceedings/EU-PVSEC-2023/4bo.16.6)
- Reports and articles related to DTU Electro's involvement are available on the Task 15 webpage (https://iea-pvps.org/research-tasks/enabling-framework-for-the-development-of-bipv/) and are in preparation for an Energy and Buildings special issue.
- Results from Task 15 will be available at www.solarcity-byplan.dk Q1 2024.

Overall, this section highlighted the project's comprehensive achievements, both in terms of technological advancements and effective dissemination of results.

6. Utilisation of project results

The results from this project significantly enhance the public's access to technical information about Building Integrated Photovoltaics (BIPV) products and systems. Representing the consensus of many international experts, these results are considered the best available knowledge in the field.

For the Construction Industry and BIPV Manufacturers:

The construction industry and BIPV manufacturers will benefit greatly from these results. The Task 15 web-page will serve as a continuously updated resource, offering advanced methodologies, tools, and materials. BIPV manufacturers, in particular, will find the project's contributions to standardization invaluable. The project has facilitated the development of more unified standards, addressing the overlap between construction sector and electrical standards. Additionally, the temperature analysis findings suggest that BIPV systems may operate at lower temperatures than previously thought, allowing for a broader selection of materials and easier compliance with standards.

For Urban and Building Planners:

Urban planners and building designers will be equipped with systematic methods for assessing the impact, as well as the economic and environmental performance of BIPV installations during the planning phase.

In the Danish Context:

In Denmark, the project's results have garnered interest from various entities including Ramboll, Rockwool, Lindab, Bygningsstyrelsen, and Energistyrelsen. These stakeholders find the results particularly useful for their operations and planning.

Contribution to Energy Policy Objectives:

Buildings account for approximately 30% of carbon emissions. By deploying BIPV, these emissions can be significantly reduced as BIPV facilitates onsite renewable energy generation, eliminating transmission losses and reducing the need for costly grid expansions. BIPV also enhances the social acceptance of renewable energy and offers environmental benefits through savings on building materials. The overarching aim of this project is to establish equal markets for BIPV and Building Applied Photovoltaics (BAPV), and DTU Electro's involvement has been instrumental in advancing this goal.

Incorporation into Teaching and Dissemination Activities:

Although no Ph.D. candidates were directly involved in this project, DTU Electro integrates the latest findings from the IEA PVPS Task 15 into its BIPV system teaching curriculum, ensuring that the newest knowledge is disseminated effectively.

7. Project conclusion and perspective

The project, as part of the larger IEA PVPS Task, has culminated in the publication of several comprehensive reports, which are either already available or in the process of being published. These reports span a wide array of topics including market analysis, cross-sectional analysis, digitalization of BIPV, and best practice guidelines. They provide valuable information and recommendations that are crucial for the deployment of BIPV, improvement of standards, and in some instances, offer guidance for government policies. Collectively, these elements contribute significantly to the qualified adoption of BIPV solutions.

Next Steps for the Researched Technology Area:

The project has laid the groundwork for the third phase of research, with a work plan that has been approved by the Executive Committee (EXCO). This next phase addresses new challenges identified in the second phase and includes ongoing research on BIPV's role in nearly zero-energy buildings, its contribution to the circular economy, and building sustainability labels. Key areas of focus will include fire safety, performance of colored BIPV, glare assessment, and shade alleviation. The digitalization of BIPV remains a priority, with ongoing research on BIPV Building Information Modeling (BIM) object standardization. Additionally, there will be continued exploration of the diversity, yield, and reliability of colored BIPV systems, alongside a dedicated subtask for dissemination and upskilling. DTU Electro plans to actively participate in a substantial portion of these activities.

Influence on Future Development:

The project has underscored the importance of international collaboration and the sharing of unified expert knowledge. This collaborative approach has not only enhanced global expertise but also fostered further international partnerships. Numerous Danish companies have expressed a significant need for such collaboration and the dissemination of knowledge it brings. The project's outcomes are expected to be a catalyst for future developments in the BIPV sector, driving innovation and adoption of sustainable energy solutions.