IEA INTERNATIONAL ENERGY AGENCY

Compilation and Analysis of User Needs for BIPV and its Functions

Report IEA PVPS T15-06: 2019

PVPS

PHOTOVOLTAIC
POWER SYSTEMS
PROGRAMME

INTERNATIONAL ENERGY AGENCY

PHOTOVOLTAIC POWER SYSTEMS PROGRAMME

Compilation and Analysis of User Needs for BIPV and its Functions

IEA PVPS Task 15

Subtask C – International framework for BIPV specifications

Report IEA PVPS T15-06: 2019

February 2019

Authors:

Simon Boddaert (Centre Scientifique et Technique du Bâtiment, France), Jessica Benson (RISE, Sweden), Pierluigi Bonomo (SUPSI, Switzerland), Véronique Delisle, (Natural Resources Canada, Canada), Christof Erban (Germany), Anna Fedorova (Norwegian University of Science and Technology, Norway), Francesco Frontini (SUPSI, Switzerland), Seiji Inoue (AGC, Japan), Hisashi Ishii (LIXIL Corporation, Japan), Konstantinos Kapsis (Natural Resources Canada, Canada), Jun-Tae Kim (Kongju National University, Korea), Peter Kovacs (RISE, Sweden), Maider Machado (Tecnalia, Spain), Nuria Martín Chivelet (CIEMAT, Spain), Eduardo Román Medina (Tecnalia, Spain), Astrid Schneider (AIT Austrian Institute of Technology, Austria), Helen Rose Wilson (Fraunhofer ISE, Germany)

Cover photo: BIPV façade of the MagicBox, developed by Universidad Politécnica de Madrid as part of the 2005 solar decathlon competition (courtesy of M.E. Caamaño-Martín).

ISBN: 978-3-906042-80-0

Contents

15th February, 2019

Helen Rose Wilson

Konstantinos Kapsis

Véronique Delisle

Editors of this report

Foreword

The International Energy Agency (IEA), founded in November 1974, is an autonomous body within the framework of the Organization for Economic Co-operation and Development (OECD), which carries out a comprehensive programme of energy co-operation among its member countries.

The IEA Photovoltaic Power Systems Programme (PVPS) is one of the technological collaboration programmes (TCP's) on research and development within the International Energy Agency (IEA). IEA PVPS has been established in 1993, and participants in the programme have been conducting a variety of joint projects regarding applications of photovoltaic (PV) conversion of solar energy into electricity.

The mission of the PVPS is "…to enhance the international collaboration efforts which accelerate the development and deployment of photovoltaic solar energy as a significant and sustainable renewable energy option…". The underlying assumption is that the market for PV systems is gradually expanding from the niche-markets of remote applications and consumer products to rapidly growing ones for building-integrated and centralised PV generation systems.

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.

Further information on the activities and results of the Task can be found at www.IEA PVPS.org.

Michiel Ritzen, operating agent IEA PVPS Task 15

February 2019

1. Introduction

This report focuses on the needs for BIPV and the multiple functions that BIPV provides from the perspective of the users. The “users” may be the building owner, the building occupants and the professionals involved in planning and constructing the building, such as the architects, engineers, consultants and contractors. Other remote “users” could also be the building supervisor, the city authorities (or other involved administrations), the investors and banking institutes financing the project, and insurance companies. Some of the needs may be identical for all of these users; others may be specific to a single user. The needs include “high-level” basic requirements as defined e.g. in the European Construction Product Regulation CPR 305/2011, but go beyond those specified in construction laws, technical standards, regulations and guidelines, to include aspects such as energy performance and energy autonomy, visual impact and interaction with the environment, aesthetics and financing risks.

Specific formulations of requirements, such as would typically be found in technical standards, regulations and guidelines, are not the subject of this report. These will be addressed in another report by Subtask C of IEA PVPS Task 15.

2. User needs

2.1 Needs concerning BIPV performance as a building component

2.1.1 Mechanical resistance and stability (of the user's building)

In the European Union, the EN 1990 Eurocode establishes *"Principles and Requirements for the safety, serviceability and durability of structures, describes the basis for their design and verification and gives guidelines for related aspects of structural reliability*".

Mechanical resistance and stability is also one of the essential requirements set in the European Union Construction Products Regulation CPR 305/2011. There are several standards defining related characteristics, as well as testing and assessment methods used to verify the fulfilment of these requirements. The CPR states the following:

"The construction works must be designed and built in such a way that the loadings that are liable to act on them during their constructions and use will not lead to any of the following:

a) collapse of the whole or part of the work;
b) major deformations to an inadmissible degree;
c) damage to other parts of the construction works or to fittings or installed equipment as a result of major deformation of the load-bearing construction;
d) damage by an event to an extent disproportionate to the original cause."

The specific loads and forces in the case of photovoltaic systems are typically the following:

- The weight of the photovoltaic system itself and its substructures and fixtures (dead weight)
- Snow loads
- Wind loads
- Seismic loads
- Hard impacts from hail or other external objects falling onto a PV module
- Soft impact caused e.g. by people falling or leaning onto a PV module
- Thermal expansion and thermal stresses
- Single-point or distributed loads from e.g. people standing or walking on the photovoltaic modules, where relevant
- Loads occurring during construction or maintenance work, e.g. cleaning or replacement of PV system components or modules
- Loads from other building parts, where applicable

In contrast to many other factors, the prevalence of snow, hail and strong winds is mainly a matter of geographical location (*Figure 1*). Specific levels in the European Union are defined in national appendices to the Eurocode EN 1990-1999 and in further national standards and building codes. The applicable load levels vary between countries and often also within a single country. For wind in particular, the loads vary also with building height and with the location of the BIPV system relative to the construction. The current EN 50583 standard reflects these circumstances and is a comprehensive compilation of standards that can be used as a reference for requirements on mechanical resistance and stability.

Figure 1: (Left) Non-uniform snow load on PV roofing slates and (right) mechanical load test imposing a uniform load onto a PV panel. (Source: SUPSI)

Requirements related to mechanical resistance and stability vary extensively depending on the application, whether as a roofing or façade element or a solar shading device. It is uncommon for a BIPV product to be designed to carry loads from other parts of the building construction although such applications could also occur, e.g. in pavements for terraces, PV glazed floors and glass roofs or in the field of structural glass construction. Furthermore, glass components, which could include BIPV glazing elements, are sometimes used to stiffen filigree load-bearing constructions.

In many applications, BIPV products require a higher load resistance and structural rigidity than standard PV modules, and even more importantly, they must provide so-called “post-breakage integrity”. This is the property that a broken BIPV element must remain safe (e.g. not fall apart or slip out of its frame) under the load for a predefined period of time. Examples of applications and such requirements are:

For roofs:
- Ability to withstand snow and wind loads
- Tolerance of loads imposed during construction and maintenance work (large roof-integrated PV areas)
- Additional load and impact resistance requirements for walk-on glazing

For vertical façade elements:
- Laminated glass or laminated safety glass properties, higher bending stiffness due to vertical installation
- Installations in high-rise buildings, requiring resistance to higher wind loads than specified in IEC standards
- Higher point load resistance due to shielding functionality
- Greater rigidity and laminated safety glass properties due to point (rather than linear) fixtures
- Laminated safety glass properties in the case of glass-glass elements

For vertical “barrier glazing” elements with a protective function such as terrace balustrades (“post-breakage integrity”):
- Laminated safety glass properties in the case of glass-glass elements

For overhead installations such as glass roofs, canopies and shading elements:
- Laminated safety glass properties in the case of glass-glass elements

References

Construction Products Regulation. (2011). CPR. Regulation (EU) 305/2011.
DIN 18008: Glass in Building – Design and construction rules (revised version due in 2018 or 2019)
DIN 18008-1:2010-12: Part 1 - terms and general bases
DIN 18008-2:2010-12: Part 2 - Linearly supported glazing
DIN 18008-3:2013-07: Part 3 - Point fixed glazing
DIN 18008-4:2013-07: Part 4 - Additional requirements for barrier glazing
DIN 18008-4:2013-07: Part 5 - Additional requirements for walk-on glazing
Eurocode. (2007a). EN 1993: Design of steel structures.
Eurocode. (2007b). EN 1997: Geotechnical design.
Eurocode. (2007c). EN 1999: Design of aluminium structures.
Eurocode. (2006a). EN 1991: Actions on structures.
Eurocode. (2006b). EN 1992: Design of concrete structures.
Eurocode. (2006c). EN 1996: Design of masonry structures.
Eurocode. (2005a). EN 1990: Basis of structural design.
Eurocode. (2005b). EN 1994: Design of composite steel and concrete structures.
Eurocode. (2005c). EN 1998: Design of structures for earthquake resistance.
Eurocode. (2004). EN 1995: Design of timber structures.
European Committee for Standardization. (2016). EN 50583-1: Photovoltaics in buildings. BIPV modules.
European Committee for Standardization. (2016). EN 50583-2: Photovoltaics in buildings. BIPV systems.
European Committee for Standardization. (2005). EN 14449: Glass in building. Laminated glass and laminated safety glass – Evaluation of conformity/product standard.

2.1.2 Water tightness

Depending on the application, certain BIPV products and systems have to guarantee waterproofing during their service life, preventing major damage to the building envelope and avoiding negative effects on indoor comfort. For example, BIPV roof tiles or shingles have to withstand waterproof tests under windy conditions like any other conventional roof structures, when installed in accordance with the manufacturer's instructions (*Figure 2*).

Typically, the manufacturer provides the various roof pitches and minimum-level requirements for roof sub-structures and underlay elements in order to guarantee this performance. In many countries, it has become common practice to install an underlay below the open-joint roof covering (primary weather barrier) as a secondary barrier to drain moisture from condensation, wind-driven rain and snow.

Figure 2: Wind-driven rain test at SUPSI. (Source: SUPSI)

2.1.3 Air tightness

The air tightness of a building has a direct impact on its energy performance, indoor air quality and on the occupants' thermal and acoustic comfort. For specific applications such as windows, doors or skylights, BIPV products might need to be tested for air tightness to ensure that the amount of air passing through a unit area is within an acceptable range. Similarly, a BIPV system replacing conventional cladding, roofing or a curtain wall system might also have to be tested for air tightness. Under specific regulations, the air tightness level also needs to be rated. The rating is then included in the product technical specification or overall performance rating. While most product standards addressing air tightness specify procedures to measure it, the required level is determined by national or regional building energy codes or by the client who wishes to fulfil a performance target or standard. An example of such a performance standard is the 'Passive house standard', for which a 'Blower door test' is mandatory.

2.1.4 Hygiene, health and the environment (for the building user)

The European CPR 305/2011 states the following:

"The construction works must be designed and built in such a way that they will, throughout their life cycle, not be a threat to the hygiene or health and safety of workers, occupants or neighbours, nor have an exceedingly high impact, over their entire life cycle, on the environmental quality or on the climate during their construction, use and demolition, in particular as a result of any of the following:

a) *the emission of toxic gas;*
b) *the emissions of dangerous substances, volatile organic compounds (VOC), greenhouse gases or dangerous particles into indoor or outdoor air;*
c) *the emission of dangerous radiation;*
d) *the release of dangerous substances into ground water, marine waters, surface waters or soil;*
e) *the release of dangerous substances into drinking water or substances which have an otherwise negative impact on drinking water;*
f) *faulty discharge of waste water, emission of flue gases or faulty disposal of solid or liquid waste;*
g) *dampness in parts of the construction works or on surfaces within the construction works."*

The building user expects BIPV to be safe, so materials that make up the laminate, the frame, the supporting structure, the junction box and cabling should comply with the requirements listed above. Toxicity of materials used in BIPV should be as low as possible (see section 2.4.4).

In addition, because BIPV modules are usually impermeable to water and vapour, just like any other glass or metal construction components, it is important that a BIPV system is constructed according to state-of-the-art construction practices to allow water and vapour diffusion control.

A number of experimental studies, as referenced below, have confirmed that the examined electromagnetic field levels due to (BI)PV installations are not dangerous and, therefore, are "no cause for concern among the public". Installed BIPV systems, being electrotechnical systems, must comply with the standards of the International Electrotechnical Commission and local standards and regulations regarding electromagnetic field levels.

References

Construction Products Regulation. (2011). CPR. Regulation (EU) 305/2011.

Guldberg, P.H. (2012). Study of acoustic and EMF levels from solar photovoltaic projects. Tech Environmental, Inc. Prepared for Massachusetts Clean Energy Center.

Heseltine, E., & Rosen, J. (Eds.). (2009). WHO guidelines for indoor air quality: dampness and mould. WHO Regional Office Europe.

Safigianni, A. S., & Tsimtsios, A. M. (2014). Electric and magnetic fields due to rooftop photovoltaic units. J. Basic Appl. Phys, 3(2), 76-80.
Tell, R. A., Hooper, H. C., Sias, G. G., Mezei, G., Hung, P., & Kavet, R. (2015). Electromagnetic Fields Associated with Commercial Solar Photovoltaic Electric Power Generating Facilities. Journal of occupational and environmental hygiene, 12(11), 795-803.

2.1.5 Safety and accessibility in use

As required by other needs (i.e. fire protection), the CPR 305/2011 specifies that construction works (such as a BIPV component) *"must be designed and built in such a way that they do not present unacceptable risks of accidents or damage in service or in operation such as slipping, falling, collision, burns, electrocution, injury from explosion and burglaries. In particular, construction works must be designed and built taking into consideration accessibility and use for disabled persons".*

These needs have also been translated into different requirements, both from the perspective of electrical safety and of construction/mechanical safety. An example is the IEC 62109-1:2010 standard that lists the following safety requirements on power converters for use in photovoltaic power systems:

a) Protection against electric shock and energy hazards
b) Protection against mechanical hazards
c) Protection against fire hazards (see also 2.1.5.2)
d) Protection against sonic pressure hazards
e) Protection against liquid hazards
f) Protection against chemical hazards
g) Indication on how to handle a PV/BIPV element (wiring, connection, etc.)

Accordingly, PV module safety standards, IEC 61730-1 and IEC 61730-2 – 'Photovoltaic (PV) module safety qualification', include test series addressing the "general inspection, electrical shock hazard, fire hazard, mechanical stress, and environmental stress".

References
Construction Products Regulation. (2011). CPR. Regulation (EU) 305/2011.
International Electrotechnical Commission. (2010). IEC 62109-1: Safety of power converters for use in photovoltaic power systems – Part 1: General requirements.
International Electrotechnical Commission. (2016). IEC 61730-1 and IEC 61730-2 - Photovoltaic (PV) module safety qualification - Part 1: Requirements for construction, - Part 2: Requirements for testing.

2.1.5.1 Protection and safety under extreme conditions

This section addresses BIPV installations located in areas subject to extreme natural phenomena (hurricanes, cyclones, seismic phenomena) or installations that require blast or impact live load protection. Under these circumstances, the user or the building code will require that the BIPV installation satisfies the relevant safety and performance standards.

Also, as part of the building energy resilience to the power outages that frequently occur during or after extreme conditions, the user might also require that the BIPV system continues feeding the building or the micro-grid with solar electricity. In this case, an interactive inverter/charger with grid forming capabilities is required, coupled with electrical storage (currently in the form of a battery bank and in the near future, through electric vehicle-to-grid technologies). At the minimum, the electrical storage unit should be sized to supply emergency loads.

2.1.5.2 Safety in case of fire (in or near the user's building)

There are several regulations for defining the fire safety characteristics. Fire safety is also one of the essential requirements set in the CPR 305/2011, which states the following:

"The construction works must be designed and built in such a way that in the event of an outbreak of fire:

a) the load-bearing capacity of the construction can be assumed for a specific period of time;
b) the generation and spread of fire and smoke within the construction works are limited;
c) the spread of fire to neighbouring construction works is limited;
d) occupants can leave the construction works or be rescued by other means;
e) the safety of rescue teams is taken into consideration."

The CPR 305/2011 demands that any BIPV products or systems used as building elements (e.g. façade cladding) should not reduce the safety of the occupants in case of fire. These performance and safety requirements have been specified in various standards and regulations as fire-relevant characteristics of a PV component or system, such as reaction to fire, fire resistance and fire propagation. For architects and building planners, it is essential to have information regarding the fire rating of the BIPV system. This includes not only the PV modules and the related substructures but also the inverters, which are not yet (as of August 2018) commercially available with a classification regarding fire standards as required for construction works.

References

Construction Products Regulation. (2011). CPR. Regulation (EU) 305/2011.

Bonomo, P., Saretta, E., Frontini, F., Caccivio, M., Bellenda, G., Manzini, G., & Cancelliere, P. (2017). Fire safety on PV modules and buildings: overviews, bottlenecks and hints. In *33rd European Photovoltaic Solar Energy Conference and Exhibition Conference. Amsterdam* (pp. 2299 – 2303).

Ishii, H., Kondo, M., Saito , M., Nakajima , A., Hayashi, M and Saito, H. (2018) Experimental Study on BIPV Module of Closed Circuit Situation Exposed to Fire. In *Grand Renewable Energy 2018 International Conference and Exhibition. Yokohama. Japan*

2.1.6 Protection against noise (interior and exterior to the building)

According to CPR 305/2011, *"The construction works must be designed and built in such a way that noise perceived by the occupants or people nearby is kept to a level that will not threaten their health and will allow them to sleep, rest and work in satisfactory conditions."* A photovoltaic module does not create any sound itself and when properly integrated in the building structure, it should not create any noise under normal wind conditions. The integration of a BIPV product into a construction work can, when properly addressed, contribute to dampening or re-directing undesired background noise, similar to the application of PV modules used as sound barriers along roads and railroad tracks.

By contrast, inverters are a potential source of noise that requires consideration. In general, the sound pressure is proportional to their size, meaning that very small (micro) inverters that are integrated into the PV modules do not cause any noise issues. Central or string inverters, however, need particular attention with respect to noise pollution, so specific information regarding noise emissions should be available.

References

Construction Products Regulation. (2011). CPR. Regulation (EU) 305/2011.

Nordmann, T., & Clavadetscher, L. (2004). PV on noise barriers. *Progress in Photovoltaics: research and applications, 12*(6), 485-495.

2.1.7 Energy economy, heat retention and comfort (during operation of building)

According to CPR 305/2011, "*The construction works and their heating, cooling, lighting and ventilation installations must be designed and built in such a way that the amount of energy they require in use shall be low, when account is taken of the occupants and of the climatic conditions of the location. Construction works must also be energy-efficient, using as little energy as possible during their construction and dismantling.*" Most industrialized countries have laws regarding the energy consumption of buildings. In Europe, the energy economy of buildings is regulated through the 'Energy Performance of Buildings Directive EPBD 2010/31/EU' in the following manner:

"Nearly zero-energy building: a building that has a very high energy performance. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby."

In the 2018 amendment of the EPBD, "on-site electricity generation" and "systems using energy from renewable sources" have been added to the definition of relevant "technical building systems", such that an approach applying PV to achieve nearly zero-energy buildings is explicitly included. An increased emphasis on electromobility as part of a holistic concept also favours the incorporation of on-site electricity generation.

More and more countries are introducing renewable energy conversion into buildings and energy codes, on a mandatory basis. BIPV systems play a major role in fulfilling the obligation to meet some or all of the building's energy demand with renewable resources. BIPV systems can even contribute to passive energy-saving strategies. For example, semitransparent PV insulated glazing units can provide thermal insulation during the winter and enhance shading during the summer (*Figure 3*).

To avoid excessive energy consumption by artificial lighting, sufficient daylight should still enter the building when BIPV products are used as substitutes for transparent areas of the building envelope. Opaque BIPV roofs and wall cladding, if properly designed and combined with insulation materials, can reduce annual heating and cooling loads compared to those for conventional building skin materials. Other approaches such as heat recovery from the rear side of the BIPV system (known as BIPVT), can also contribute to improve the overall building energy efficiency.

BIPV systems should always be designed and installed to enhance or maintain the thermal, visual and acoustic comfort of the occupants. Thermal comfort is usually ensured when the thermal insulation level of the building envelope, including those areas occupied by BIPV, is high. Visual comfort is a more complex issue and it should be considered thoroughly when BIPV systems are used as light-transmitting or solar-shading elements. Semi-transparent BIPV elements can contribute to solar control and daylighting (*Figure 4*). During the design of such systems, the aspects of visual contact with the exterior, glare control, contrast requirements, required luminance and illuminance levels, light transmission homogeneity, colour rendering and optional room darkening should be taken into account. Daylight simulations or physical models can help in addressing these issues (see Section 2.2.3).

References

Baenas, T., Machado, M. (2017), "On the analytical calculation of the solar heat gain coefficient of a BIPV module", *Energy and Buildings* 151, 146-156.

Chatzipanagi, A., Frontini, F., & Virtuani, A. (2016). BIPV-temp: A demonstrative Building Integrated Photovoltaic installation. *Applied Energy*, 173, 1–12.

Construction Products Regulation. (2011). CPR. Regulation (EU) 305/2011.

Energy Performance of Buildings Directive. (2010). EPBD. Directive (EU) 31/2010.

EPBD Amendment (2018). Directive (EU) 2018/844

Ishii, H. (2017). Thermal Performance (G-Value and U-Value) - Evaluation of BIPV Applied to Glass Façade. *In 33rd European Photovoltaic Solar Energy Conference and Exhibition Conference. Amsterdam*.

Kuhn, T. E. (2017). State of the art of advanced solar control devices for buildings. *Solar Energy*, 154, 112-133.

Mach, T., Grobbauer, M., Streicher, W., & Müller, J. M. (2015). mppf-The Multifunctional Plug&Play Approach In Facade Technology. Verlag der Technischen Universität Graz. Markvart, J., Iversen, A., Logadóttir, Á., & Johnsen, K. (2012). Indoor light and visual comfort with solar cells in glass facades. *Aalborg university*.

Moralejo-Vázquez, F.J., Martín-Chivelet, N., Olivieri, L., and Caamaño-Martín, E. (2015) Luminous and solar characterization of PV modules for building integration, *Energy and Buildings,* 103, 326–337.

Olivieri, L., Caamaño-Martín, E, Moralejo-Vázquez, F.J., Martín Chivelet, N., Olivieri, F., Neila-González, J. (2014). Energy saving potential of semi-transparent photovoltaic elements for building integration. *Energy* 76, 572-583.

Olivieri, L., Frontini, F., Polo-López, C., Pahud, D., & Caamaño-Martín, E. (2015). G-value indoor characterization of semi-transparent photovoltaic elements for building integration: New equipment and methodology. *Energy and Buildings, 101*, 84-94.

Rennhofer, M., Berger, K., Leidl, R. (2012). Photometric Evaluation of Photovoltaic Thin-Film Shading Elements. *Proc. 27th European Photovoltaic Solar Energy Conference*, Frankfurt.

Figure 3: Semi-transparent module can be used in different parts of a façade or a roof to reduce the light and solar transmittance of windows or curtain walls while generating solar electricity. Low-energy house with semitransparent BIPV windows at SUPSI (left), and SMART-flex EU project (centre) and BIPV façade at CSTB facility (right).

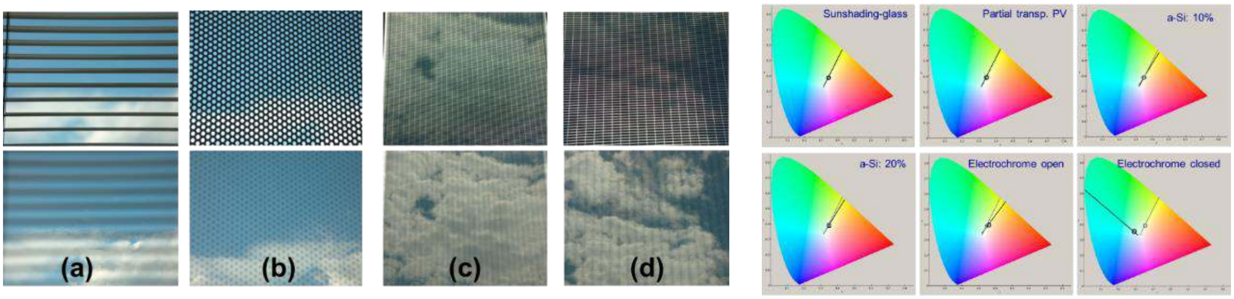

Figure 4: Various semitransparent thin-film BIPV glazing units (a to d) can offer optimal shading and daylighting conditions with minimum impact on the colour rendering properties of the window. [Mach et al.(2015)]

2.2 Needs concerning BIPV as an electricity generator

2.2.1 Electricity for local use (self-consumption)

Under IEA PVPS Task 1 "Strategic PV Analysis & Outreach", self-consumption is defined as the local use of solar-generated electricity to reduce the amount of electricity purchased from the grid. For BIPV, the self-consumption ratio is the fraction of BIPV electricity generation consumed by the user without relying on the grid infrastructure for balancing. The consumption can be done at the moment of generation or at a later time, if the system has a storage system such as a battery bank. Thus, the self-consumption ratio can be anywhere between 0 and 1 depending on the user load profile, the BIPV system size and the presence (or absence) of a storage system. The desired ratio can be achieved by: i) applying demand side management (DSM) ii) improving/shifting the consumption profile to better match the solar electricity generation and iii) using an energy (electrical or thermal) storage system. The BIPV design also plays a role in the self-consumption ratio: the building surfaces, where the BIPV modules are integrated, should be chosen after considering the best matching solution between the building's electricity load curve and the photovoltaic (PV) generation profile. The desired ratio will have a direct impact on the capital investment, the dimensioning of the BIPV and energy storage systems, and the design of the power management system.

Self-consumption of solar electricity is a major economic motivation for BIPV systems today, as feed-in tariffs are vanishing and self-consumption of the generated solar power is the main financial source – via the reduced electric power bill – to amortize the photovoltaic system investment. An additional advantage is that self-consumption can also contribute to lessen the burden on medium-voltage and low-voltage grids. To succeed in this task, a good balance between load control, battery charging and grid export is needed. These systems are mostly grid-connected, but aim to achieve a high rate of self-supply.

In locations with no access to a public electricity grid, such as in remote locations or regions of the world without a power grid (or with an unreliable grid), self-consumption of solar generated electricity is the fundamental reason to install a (BI)PV system as part of a microgrid, mostly in connection with batteries and other sources of energy. Other drivers include the desire for resiliency in case of crisis and the need to reduce the reliance on fossil fuels.

References

Macé, P., Larsson D., & Benson, J. (2018). Inventory on Existing Business Models, Opportunities and Issues for BIPV. *International Energy Agency Photovoltaic Power Systems Programme Task 15*.

Martín-Chivelet, N., & Montero-Gómez, D. (2017). Optimizing photovoltaic self-consumption in office buildings. *Energy and Buildings, 150*, 71-80.

Masson, G., Briano, J.I., & Baez, M.J. (Eds.). (2016). A methodology for the analysis of PV self-consumption policies. *Photovoltaic Power Systems Programme Task 1*.

2.2.2 Energy self-sufficiency

Whereas Section 2.2.1 addresses the user's need to have electricity available *per se* (some of which will probably still be from the power grid), self-sufficiency implies that the BIPV system supplies all the electricity demand of the building(s), at least for a specified minimum duration (e.g. for time-of-use pricing). This need for independence from the power grid may be due to remoteness of the location, the high risk of natural or man-made catastrophes (see Section 2.1.5.1) and/or the importance of an uninterruptable power supply to critical loads (e.g. hospitals, data centres). This need will have consequences for the dimensioning of the BIPV system, since additional components such as electrical storage units and a power management system may be required.

2.2.3 Applying simulation for reliable prediction of generated power

During the design and planning phase of a BIPV system, it is important that the solar energy output of the system be predicted with a certain accuracy by taking into account not only the interactions with the surrounding environment but also the interactions between the BIPV system and the building.
BIPV installed in urban areas is susceptible to shadows cast by surrounding buildings. However, a BIPV system could benefit from light reflected by snow or surrounding buildings. As part of the building skin, BIPV has a direct impact on the cooling, heating and electric lighting loads as well as occupant comfort. All these interactions can be assessed using building or PV performance simulation tools. Currently, some commercially available simulation tools either incorporate BIPV modelling capabilities (*Figure 5*) or allow the user to develop customized BIPV models.

Simulations can also be used for risk assessment by predicting the glare caused by the BIPV façade to the surrounding environment (see Section 2.4.5) or for decision support related to demand response, self-consumption and return-on-investment. Therefore, it is important that BIPV simulation studies are always incorporated into the design process to predict solar power and energy generation and capture the impact of BIPV on the building energy performance, occupant comfort and the surrounding environment.

References

Fath, K. (2018). Technical and Economic Potential for Photovoltaic Systems on Buildings. *Karlsruhe Institute of Technology*.

Ishii, H. (2017). Thermal Performance (G-Value and U-Value) - Evaluation of BIPV Applied to Glass Façade. *In 33rd European Photovoltaic Solar Energy Conference and Exhibition Conference. Amsterdam*.

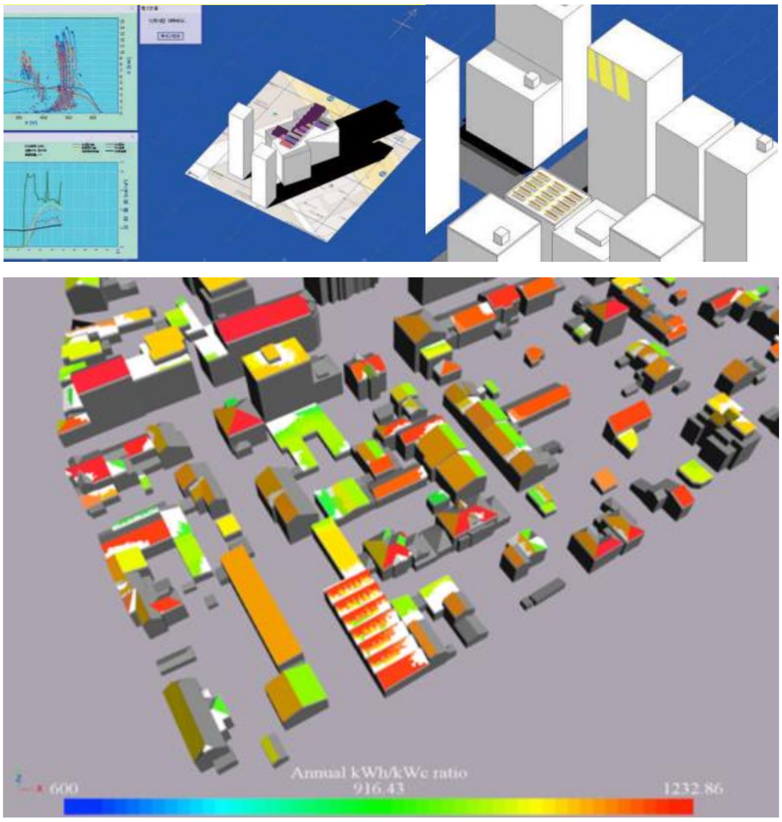

Figure 5: Simulated irradiance on the building envelope for prediction of generated power [https://www.lapsys.co.jp/english/products/pro.html] (top) and simulated annual solar energy on rooftops of a neighbourhood [https://www.cstb.fr] (bottom).

2.3 Needs concerning long-term BIPV operation

2.3.1 Durability and reliability

Ideally, a BIPV system should operate throughout the lifetime of the building. Also, the user expects that the BIPV should retain all functions as both a building component and an electricity generator. The typical guarantee period for the electrical performance of a standard PV module is between 20 and 30 years. However, in practice, the lifetime expectancy can be between 25 to 35 or even 30 to 40 years. If a BIPV module fails electrically, it may have to be replaced even if it is still functional as a building component. Conversely, if a BIPV element suffers from mechanical damage, it may be necessary to replace it even though it is still electrically functional.

The expectations on durability for BIPV modules may be greater than for standard modules because replacement of a failed module is often more complex when it is building-integrated than when it is building-applied.
In order to meet these needs, BIPV modules (including their encapsulating and sealing components) should have at least the same level of durability and reliability for each function (e.g. mechanical resistance, UV resistance, safety, electrical property, water and air tightness) as equivalent conventional building materials (materials without electricity-generating functions).

2.3.2 Ease of maintenance

A building may be seen as a composition of various elements, so-called maintenance-source elements (MSE). Each MSE has its own degradation mechanism and performance characteristics, from which the need for maintenance could be evaluated. During the service lifetime of the BIPV system, maintenance work is also required to ensure proper performance. Maintenance must be done without compromising either the comfort or safety of inhabitants or the building itself, while the architectural aesthetics of an installation should remain the same or be improved.

Maintenance of BIPV could include: cleaning dust, dirt, snow or ice from the surface of the BIPV modules, replacing one or several failed or damaged modules, replacing components of the mounting system, maintenance of Balance-of-System (BoS), etc. The effort for maintenance greatly depends on the method of integration and the part of the building envelope where the BIPV is used as well as the local climate. The cost of BIPV maintenance should be comparable to the maintenance cost of similar building envelope components.

The people carrying out the maintenance should be trained for their tasks and be aware of both the electricity-generating and the building-related features of a BIPV system. To perform BIPV maintenance, it is easier and more cost-effective when standardized modules (by size and shape) are used and a maintenance plan is provided. To optimize the operational costs, the various maintenance issues should be considered at the early design stages. Inspection of the system and maintenance should be performed at least once a year, while monitoring of the system performance should be ongoing during the whole service lifetime.

Referring to Section 2.3.1, both the durability and the reliability of the system affect the need for maintenance. The longer a BIPV system provides the combined functions of electricity generation and building component, the less maintenance work and additional expenses will be needed. Conversely, adequate maintenance including early detection and repair of minor faults can increase the service lifetime of a BIPV installation.

BIPV system producers and planners should take maintenance of the BIPV system into account during the system design phase. The amount and type of maintenance needed will depend on the climatic conditions at the location of the installation. The following issues should be considered and specified:

- Accessibility of the BIPV system
- Provision for walking on BIPV roofs for maintenance purposes
- Feasibility of replacing single modules (of BIPV roofs or façades), which may be facilitated by the development of plug-and-play BIPV systems
- Tolerance to shading of BIPV modules, when cleaned or maintained during the day
- Surface cleaning instructions and tools required (water, soaps, removal of algae or soiling)

2.3.3 Protection against theft

When a BIPV module is an integrated element of the building envelope, the risk of theft is lower than for a ground-mounted or building-applied PV system. Nonetheless, the choice of mounting fixtures that prevent the BIPV modules from being easily detached may be advisable for locations where the risk of theft is high.

2.3.4 Protection against vandalism

If they are easily accessible, BIPV modules may be a target for graffiti or damage. The need for protection against vandalism could be met by precautions such as application of anti-soiling coatings or use of safety glass. Also, accessibility can be reduced by mounting the modules above the ground-storey level.

2.4 Needs concerning visual impact and interaction with the environment

2.4.1 Aesthetically pleasing building appearance

Although there are no universal criteria applicable to all contexts referring to "aesthetically pleasing building appearance", as this concept involves a certain degree of subjectivity, some approaches to defining "good aesthetic integration" or "good architectural design" are given in the references.

For instance, IEA SHC Task 41 on "Solar Energy and Architecture" suggests some integration criteria and guidelines:

"All the PV characteristics affecting the building's appearance should be coherent with the overall building's design, for example:

- *The position and dimension of the modules have to be coherent with the architectural composition of the whole building.*
- *Visible material(s), surface texture(s) and colour(s) of the PV modules should be compatible with the other building skin materials, colours and textures with which they are interacting.*
- *Module size and shape have to be compatible with the building composition grid and with the various dimensions of the other facade elements.*
- *Jointing types must be carefully considered while choosing the product, as different jointing types emphasise the modular grid of the system to different extents in relation to the building."*

"For completely successful integration, all these characteristics should be coherent with the overall building design logic. Consequently, the more flexibility offered by a product for each characteristic, the easier the integration work for the architect."

References

Bonomo, P., Chatzipanagi, A., & Frontini, F. (2015). Overview and analysis of current BIPV products: new criteria for supporting the technological transfer in the building sector. *Journal of Architectural Technology and Sustainability*, (1), 67-85.

Farkas, K., Frontini, F., Maturi, L., Munari Probst, M. C., Roecker, C., & Scognamiglio, A. (2013). Designing photovoltaic systems for architectural integration. *International Energy Agency Solar Heating and Cooling Programme Task 41.*

Probst, M., & Roecker, M.C. (Eds.). (2013). Solar energy systems in Architecture - Integration criteria and guidelines. *International Energy Agency Solar Heating and Cooling Programme Task 41.*

2.4.2 Flexibility in module dimensioning

Photovoltaic modules to be integrated into buildings must fulfil many purposes, whether they are integrated into façades, roofs or other parts of the building. On the one hand, they should be integrated aesthetically and on the other hand, structurally and functionally. To fulfil these requirements, the PV module must fit into:

- Modular dimensions of the building's structure or design
- Window glazing units
- Glass façade elements
- Spaces near the edges of façades or roofs
- Spaces between other building elements

In building renovation, the need to adapt the PV module form to given structures, spaces and dimensions is very important. Even in new buildings, it is surprising how many different module forms and sizes are required. Such an example is the 100 kWp double curved glass roof of the Berlin main station, where each PV module has a different size and shape. This variation could cause two issues:

i) increased cost for manufacturing and installation due to customization and ii) increased cost due to individual module certification (for EU according to IEC 61215 and IEC 61730).

As an alternative and less expensive approach, the user should be able to choose standardised BIPV products that are designed to fit into different shapes and sizes of roofs or façades. An example is PV roof shingle products with small formats that fit into various geometrical configurations. Supplementary elements without active photovoltaics ("dummy" modules) allow such systems to be integrated into various areas of the building envelope, including shaded zones.

References

International Electrotechnical Commission. (2010). IEC 62109-1: Safety of power converters for use in photovoltaic power systems – Part 1: General requirements.

International Electrotechnical Commission. (2016). IEC 61730-1 - Photovoltaic (PV) module safety qualification - Part 1: Requirements for construction.

International Electrotechnical Commission. (2016). IEC 61730-2 - Photovoltaic (PV) module safety qualification - Part 2: Requirements for testing.

2.4.3 Visible expression of "green" values / corporate image

Green buildings provide financial benefits and enhance the image of a company by portraying the environmentally friendly nature of an organization. Publicly displayed photovoltaic technology such as BIPV systems can impart the environmental commitment and sustainability goals of the company to the public. In addition, the use of BIPV technology can also contribute to green building certification according to assessment methods such as LEED, BREEAM and Passive House, while shifting a building energy balance toward neutrality.

References

Macé, P., Larsson D., & Benson, J. (2018). Inventory on Existing Business Models, Opportunities and Issues for BIPV. *International Energy Agency Photovoltaic Power Systems Programme Task 15*.

2.4.4 Sustainable use of natural resources (during complete building life cycle)

According to CPR 305/2011, *"the construction works must be designed, built and demolished in such a way that the use of natural resources is sustainable and in particular ensure the following:*

a) reuse or recyclability of the construction works, their materials and parts after demolition;
b) durability of the construction works;
c) use of environmentally compatible raw and secondary materials in the construction works."

An environmentally aware owner or user of a BIPV system expects the system to be sustainable throughout its complete life cycle, i.e. "*from raw material acquisition or generation from natural resources to final disposal*".

Specifically, the use of toxic materials or significant amounts of rare materials should be avoided (when possible), and the products should be designed such that they can readily be separated into their components to the level needed for effective recycling. A BIPV system, which by definition replaces a "conventional" construction product, consumes less material and energy for its fabrication than an equivalent BAPV system and the building components needed to provide the same dual functionality as the BIPV system. Finally, solar electricity, when combined with effective energy management, can offset the consumption of electricity generated by non-renewable sources.

References
Construction Products Regulation. (2011). Regulation (EU) CPR 305/2011.
Frischknecht, R., Itten, R., Sinha, P., de Wild-Scholten, M., & Zhang, J. (2015). Life cycle inventories and life cycle assessments of photovoltaic systems. *International Energy Agency Photovoltaic Power Systems Programme Task 12.*

2.4.5. Minimisation of disturbing reflection

Similar to all glazed or reflective building surfaces, when sunlight strikes BIPV modules installed on a façade, it can cause glare and heating of the surroundings (Figure 6). Such phenomena are already well known and should be considered in design guidelines. A reflected light issue often becomes evident only after completion of construction. Thus, design plans should consider the building morphology, the surrounding environment and the materials used, from the early design stages. For example, since BIPV is often composed of glass, it is necessary to understand its optical properties. While the reflectance of a glass-air surface is about 4% at normal incidence, it increases significantly as the incidence angle increases, especially at angles exceeding 60°. In addition, the reflectance from metal contacts and connectors can be higher; but this can be reduced by colouring them black with special coatings or tapes. As the relative area of contacts and connectors is small, this increased reflectance may be disturbing at an aesthetic level, particularly if a homogenous dark surface is desired, but its physical effect with regard to glare or overheating is minimal. Anti-reflective coatings are commonly applied to the surface of PV glass to reduce the amount of reflected solar radiation and increase electrical efficiency. These coatings only reduce glare from a BIPV façade to a certain extent. Studying the path and intensity of light reflected by a BIPV façade, at the early design stages, remains the most effective way to remove or reduce glare and other disturbing reflections (see Section 2.2.3).

In order to investigate the trajectory of the reflected light, the relative location of the sun and the surrounding environment is important. The relative position of the sun changes greatly with the BIPV location and orientation, season and time of day. Technical standards regarding glare are already in place in different countries such as Germany and Austria. Until recently, these were mostly applied to photovoltaic arrays, e.g. PV arrays located near highways. However, BIPV systems are also treated as electricity generators and are partly subject to regulations applying to machinery, so calculations regarding the reflection and expected glare must be performed to obtain a building permit. Such calculations are being demanded increasingly often for large-scale applications, mainly by local authorities. Some might require an 'assessment of environmental effects' for installation of an electricity generator such as a BIPV system.

Figure 6: Sunlight reflection on glass façade [Ishii, et.al. What's a BIPV, Solar Design Consortium, July 2015]

2.5 Economic needs

From a purely economic perspective, the analysis of user needs is a complex exercise. In some cases, the initial investment for a BIPV system can be higher than that for the combination of BAPV with the conventional building component that is replaced. Thus, a first need arises in terms of Capital Expenditure (CAPEX) or initial investment for these BIPV systems: the additional cost of a BIPV system should be as low as possible, and ideally, it should be recovered within a reasonable period, with a Payback Time (PBT) of 5-10 years. A financial return on investment (ROI) of a BIPV installation can be achieved through: (1) savings in the electricity bill due to self-consumption of the generated electricity and (2) building energy savings, due to the multifunctionality of BIPV. For example, the indoor climate and energy performance may be improved and the HVAC energy consumption reduced, e.g. due to a lower g value than that of the replaced building component in a cooling-dominated climate. These effects are more evident in buildings with large glass surfaces, e.g. office buildings or malls, in which a façade BIPV system can contribute to improve the energy performance, lowering the HVAC energy demand. In general, a higher electricity yield from the BIPV installation is beneficial, but the effect of the yield on economic viability depends also on the distribution of generation over time and the local grid tariff structures.

The PBT analysis is the most commonly used approach to analyse the market potential of a BIPV installation. Alternatively, the Net Present Value (NPV) or Life Cycle Costing (LCC) methods can be applied to determine the overall financial benefit or cost of a BIPV installation over its entire life-cycle, which is often assumed to be 25 years. More sophisticated approaches can also be implemented in order to calculate the added value of a BIPV system to the building sale price or rental. According to the recent report entitled "*Inventory on Existing Business Models, Opportunities and Issues for BIPV*", published in April 2018 by the IEA PVPS Task 15, Subtask B, the cost of a BIPV installation compared to the total cost of a new building is only 1-2 % of the building cost for large BIPV façades. In the case of building rental, it is very likely that the tenant pays the bills for the facilities (electricity, water, air conditioning) and benefits economically from the BIPV system (e.g. self-consumption of PV electricity). In this case, the property owner can request a higher rent as the building could be classified as premium. At present, there is consensus that the added value of a BIPV system is very complex to calculate, but it is a parameter to be considered that requires further attention by experts.

An additional need related to EU countries, which is both regulatory and economic, should also be mentioned. Currently, European organisations are involved in the final negotiation stages regarding the Winter Package – Clean Energy for All, in which important modifications within a set of directives and legal texts related to energy and efficiency are being discussed. For instance, in the final text of the Energy Efficiency Directive (EED), it is stated that "*measures promoting the installation of small-scale solar technologies on or in buildings can be accounted towards the fulfilment of the 0,8% annual saving target, which will foster the development of smarter and cleaner buildings, powered by solar*" and "*Member States shall require the use of minimum levels of energy from renewable sources or generation installations in new buildings and in buildings subject to major renovation*". In other words, the electricity generated in-situ will be taken into account when the building energy efficiency is assessed, thus contributing to the fulfilment of the main objective of another important directive, the Energy Performance in Buildings Directive (EPBD 2010/31/EU). The EPBD establishes the obligation for all new buildings to be near Zero-Energy Buildings (nZEB) from 2020 onward (starting already in 2019 for public buildings and in 2025 for refurbished ones).

References

Energy Performance of Buildings Directive (2010). EPBD. *Directive (EU) 31/2010*.

Fath, K., Stengel, J., Sprenger, W., Wilson, H. R., Schultmann, F., & Kuhn, T. E. (2015). A method for predicting the economic potential of (building-integrated) photovoltaics in urban areas based on hourly Radiance simulations. Solar Energy, 116, 357-370.

Macé, P., Larsson D., & Benson, J. (2018). Inventory on Existing Business Models, Opportunities and Issues for BIPV. International Energy Agency Photovoltaic Power Systems Programme Task 15.

SolarPower Europe. (2018a, June 21). European co-legislators seal ambitious deals over Energy Union Governance Regulation and Energy Efficiency Directive. *SolarPower Europe Newsletter,* Retrieved from http://www.solarpowereurope.org.

SolarPower Europe. (2018b, June 14). Sunny deal on the European Renewable Energy Directive. *SolarPower Europe Newsletter,* Retrieved from http://www.solarpowereurope.org.

2.6 Declaration of Performance

A specific need regarding BIPV systems is for relevant information about the building-related properties of a BIPV product. The 'Declaration of Performance' should allow:

- The involved architects to compare the product properties with the design requirements
- The civil engineers to include the BIPV elements, products or systems into their engineering calculations regarding the structural safety of the building
- The mechanical engineers to include the optical, thermal and electrical properties into the building design and the technical plant dimensioning and selection.

The 'Declaration of Performance' of a BIPV product should include at least the following information:

a) Electrical and other properties according to IEC 61215 and IEC 61730. The safety declaration according to IEC 61730 has been a mandatory requirement in Europe since 2016.

b) Construction product information and certification addressing:
   - Mechanical properties, e.g. load resistance
   - Fire safety
   - Optical and thermal properties, e.g. colour, reflectance (where relevant)

References

Construction Products Regulation. (2011). CPR. Regulation (EU) 305/2011.

International Electrotechnical Commission. (2010). IEC 62109-1: Safety of power converters for use in photovoltaic power systems – Part 1: General requirements.

International Electrotechnical Commission. (2016). IEC 61730-1 - Photovoltaic (PV) module safety qualification - Part 1: Requirements for construction.

International Electrotechnical Commission. (2016). IEC 61730-2 - Photovoltaic (PV) module safety qualification - Part 2: Requirements for testing.

Low Voltage Directive. (2014) LVD 35/2014. Directive (EU) No. 35.

3. Analysis of user needs

BIPV user needs can be structured as illustrated in Table 1. This classification is intended to guide activities in Subtask C in developing a framework for international standardization, starting from the perspective of the BIPV user, i.e. the building constructor, the building owner and/or the building occupants.

Table 1: Classification of BIPV user needs with reference to international standardization.

Category			Item
Needs	Technical *	More International	Mechanical resistance and stability (of the user's building)
			Water tightness
			Air tightness
			Hygiene, health and the environment (for the building user)
			Safety and accessibility in use
			Protection against noise (inside and outside the building)
			Energy economy and heat retention (during operation of building)
			Electricity for consumption by user
			Reliable prediction of power generated applying simulation
			Durability/Reliability
			Ease of maintenance
			Protection against theft
			Protection against vandalism
			Flexibility in module dimensioning
			Sustainable use of natural resources (during complete building life cycle)
			Minimisation of disturbing reflection
			Declaration of performance
		More Local	Protection and safety under extreme conditions
			Safety in case of fire (in or near the user's building)
	Non-technical		BIPV self-sufficiency
			Aesthetically pleasing building appearance
			Visible expression of "green" values / corporate image
			Economic needs

*Scope of IEA PVPS Task 15 Subtask C (international standardization of BIPV)

The BIPV user needs can be categorized into technical and non-technical needs. Non-technical needs are difficult to specify in a standard. Even among the technical needs, safety needs may have to be addressed more locally, depending on the region or country.

These types of needs are not suitable for detailed specification in international standards. In a general sense, “more local” could apply to several of these needs but still should not be left out of the scope of an international standard. Instead, they should be included as far as international agreement can possibly be reached, but then complemented with national/regional or local add-ons or limitations to their content. Therefore, Subtask C should focus on the technical needs in Table 1 that can be addressed at an international level.

4. Conclusion

Viewed from the perspective of users of BIPV modules and systems, a range of needs has been identified and presented. Considering the context of Subtask C within IEA PVPS Task 15, namely to provide an "international framework for BIPV specifications", the analysis of these user needs in Chapter 3 focussed on classifying them according to their suitability for treatment within an international framework for standardisation. A more detailed technical discussion with reference to existing standards and their classification (mandatory, non-mandatory, test method, pass/fail criteria) will be included in the report on Activity C2, "BIPV technical requirements overview".

IEA INTERNATIONAL ENERGY AGENCY

9 783906 042800 >