University of Applied Sciences and Arts
of Southern Switzerland

SUPSI

CSIR-NIIST

Indian Building Integrated Photovoltaics (BIPV) Report 2022: Status and Roadmap

Status Report
2022

Report by

SUPSI-Swiss BIPV Competence Centre
Paolo Corti, Pierluigi Bonomo

The here involved Institute for Applied Sustainability to the Built Environment (ISAAC) is part of the University of Applied Sciences of Southern Switzerland (SUPSI). The institute, under ISO 9001 accreditation, covers several research areas in the field of renewable energy, rational use of building energy with particular attention to green building standards, building maintenance and refurbishment, as well as technological development.
The building sector is active in the field of research concerning building operation, advanced solar building skin, sustainable materials and constructions. The Research unit, with almost 20 years of experience in BIPV, is one of the leader groups active in federal, European and international projects of applied research, including R&D, services at industries, communication and sensitization. The team is active in global experts groups of International Energy Agency, in scientific expert committees for international conferences and journals, in standardization bodies and in the main networks supporting BIPV. The Institute also has a PVlab covering a wide range of electrical, climatic and mechanical tests according to IEC– standards and accredited ISO 17025.
The main research activities of ISAAC and specifically of the BIPV group are focused on:

- Applied R&D for developing, testing, validating, demonstrating and industrializing innovative construction solutions for multifunctional building envelope systems, conceived designed and engineered on the basis of an integrated approach;
- Developing, in collaboration with partners (architects, industries, real estate managers, etc.), innovative pilot buildings integrating PV with the role of building skin components;
- Methodologies and techniques that favor the exploitation of solar energy in the built environment, both for new and existing building stock, by analysing the techno-economic feasibility, the market needs and innovation trends;
- Development of a digitized and integrated process within the BIM-based approach involved simulation and analysis of BIPV systems

CSIR-National Institute for Interdisciplinary Science and Technology
Animesh M Ramachandran, Adersh Asok

CSIR-National Institute for Interdisciplinary Science and Technology (NIIST), is a constituent Laboratory of the Council of Scientific and Industrial Research (CSIR), New Delhi, India. CSIR, established in 1942, is an autonomous society whose Presidential position is carried by the Prime Minister of India. It holds one of the largest R&D conglomerates in the world with a dynamic pan-India network of 38 national laboratories, 39 outreach centres, 3 Innovation Complexes and 5 units located across India. CSIR, known for its cutting edge R&D knowledge-base in diverse S&T areas, is a contemporary R&D organization and categorized amongst the foremost scientific and industrial organizations in the world. CSIR is ranked at 84th among 4,851 institutions worldwide and is the only Indian organization among the top 100 global institutions, according to the Scimago Institutions Ranking World Report 2014 (CSIR holds the 17th rank in Asia and leads the country at the first position).
CSIR-NIIST, one of the prime laboratory of the CSIR conglomerate is located at Thiruvananthapuram, Kerala, the south most part of India. CSIR-NIIST is mandated to conduct interdisciplinary research and development activities of the highest quality in areas related to the effective utilisation of resources of the region and of fundamental importance to the country. Apart from fundamental research of interdisciplinary nature, technology-based interventions have been greatly carried out in the last decade, especially in the field of solar energy. Innovative technological approaches like planar light concentrators, building integrated agrivoltaics, dynamic power windows, organic and inorganic hybrid solar cells, etc., can be mentioned as a few in the BIPV headway. The institute has already established and functionalised state-of-the-art facilities for conducting advanced research in the area of interest.

University of Applied Sciences and Arts
of Southern Switzerland
SUPSI

Council of Scientific & Industrial Research –
National Institute for Interdisciplinary Science and Technology
(CSIR–NIIST)

Table of content

Chapter 2
Solar constructions

2.1 Green building revolution and role of BIPV

The real estate sector in India is the second-highest employment generator in India after the agriculture sector. In the coming years, rapid growth in the construction market and the adoption of state-of-the-art construction technologies are expected in India. More specifically, by 2024, the real estate market will grow to about 9 US$ billion, with a high Compound Annual Growth Rate (CAGR) of 19.5% from 2017-2028 is expected [1]. The current housing shortage in India's urban areas is estimated to be about 10 million units; thus an additional 25 million units of affordable housing are required by 2030 to meet the demand of growing urban population [2].

Worldwide, buildings account for nearly 39% of annual CO2 emissions, among this 28% is related to building operations and 11% to building materials and construction [3]. The high energetic footprint of the construction sector emphasises the need for introducing strategies to reduce the energy impact on buildings. To address these issues, the World Green Building Council has launched 'Advancing Net Zero' worldwide to promote and accelerate the growth of net-zero carbon buildings to 100% by 2050. According to the World Green Building Trends 2021 report by Dodge Data and Analytics, India is expected to raise the green building sector from 12% in 2021 to 25% by 2025 (survey conducted within respondents having more than 60% green projects) [4]. However, according to the report, the Indian green building sector is driven mainly by the country's environmental regulations rather than the market or public awareness. The lack of trained/educated green building professionals and unaffordability in every building sector constitute the major hindrances in the Indian green building sector. Currently, the market of green buildings in India has been concentrated in new commercial, institutional and large residential spaces.

Different green building rating systems have been introduced worldwide to promote net-zero building strategies with certificates, incentives and financial assistance. Three rating systems are predominantly existing in India: 1) Globally framed Leadership in Energy and Environmental Design (LEED), 2) rating system of Indian Green Building Council (IGBC), and 3) Green Rating for Integrated Habitat Assessment (GRIHA) of MNRE. The IGBC was formed in 2001 under the Confederation of Indian Industry (CII), which was one of the initial revolutionary course. Through the years IGBC promoted green revolution ranging from buildings, industries, cities and other habitats with individual ratings (with the involvement of key stakeholders including architects, builders, consultants, developers, owners, institutions, manufacturers and industry representatives), certification, training programs and green energy building conferences.

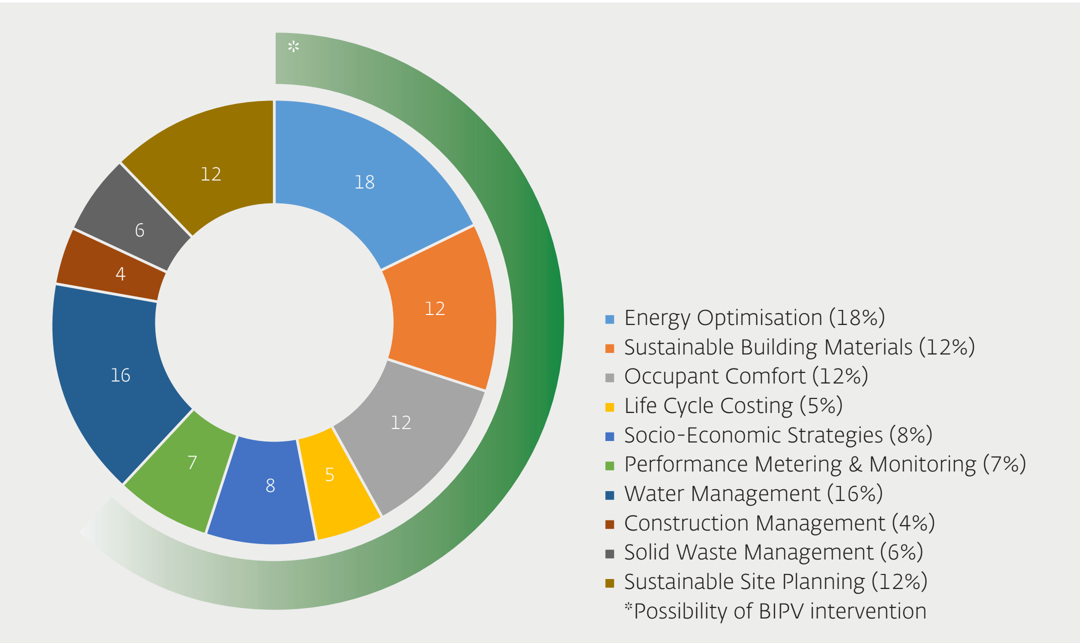
Also, MNRE has been widely promoting programmes and regulations for energy efficiency in the building environment to advocate the concept of self-sustenance, both in resources and energy, in the country. The national rating system GRIHA was developed by The Energy and Resources Institute (TERI) and endorsed by the ministry in 2007 with modifications as suggested by a panel of architects, builders, renewable energy and sustainability experts. GRIHA has been developed to rate commercial, institutional and residential buildings in India emphasising national environmental concerns, regional climatic conditions (building design considerations are done based on the six climatic zones, according to a study conducted by IIT Delhi, and adopted by MNRE), and indigenous solutions. It is a more holistic and life-cycle approach (from site selection to planning, construction and demolition) with an objective to reduce resource consumption, reduce greenhouse gas emissions and promote the use of renewable and recycled resources in buildings to rate the "greenness" of a building. It integrates all relevant Indian building codes (National Building Code 2005; the Energy Conservation Building Code (ECBC) 2007 announced by Bureau of Energy Efficiency (BEE), and other Indian Standards [5].

GRIHA has a 5-star rating system, evaluated with a set of criteria included for aspects of design, construction and operation of a green building. The pre-assigned points for each criterion are calculated with benchmark performance goals and added up to obtain the star rating. GRIHA rating is applicable for all newly constructing habitable building typologies (Residential, Healthcare, Hospitality, Institution, Office, Retail, Transit Terminals, etc.) with a minimum built-up area of 2,500 m2. Other GRIHA ratings are adopted for less built-up area buildings (Simple Versatile Affordable GRIHA), existing buildings, existing schools, large developments, etc. According to the rating directives of GRIHA [6] around 42% of point share is dedicated to Energy Optimisation (18%), Occupant Comfort (12%) and Sustainable Building Materials categories (12%). Thus, the GRIHA rating can be considered as a technical tool for green building development in India. Even though renewable energy utilization constitutes 5% of it, BIPV integration has enumerate possibilities and advantages in the mentioned categories, other than energy generation, such as:

- Passive solar construction techniques including material, architectural design and product design interventions through BIPV products
- Energy savings through PV integrated daylighting systems
- Energy conservation through thermally insulated BIPV roof and facade
- BIPV products that can offer both visual, thermal and acoustic comfort as per Indian standards
- Utilisation of alternative materials in building using BIPV, prefabrication and modular construction: Offsite construction of building components and its onsite assembly is an upcoming approach for green building construction. Prefabricated structural construction and modular assembly can be greatly congruent with BIPV elements such as building skin as façades, glazing, external roofing, etc. It greatly reduces the material consumption of conventional building construction, reduces its wastage, induce safer working conditions, reduces the time of construction, and can provide better energy and comfort performance in line with the BIPV product specifications, expanding provision for higher GRIHA rating.

Other possibilities of BIPV interventions in the GRIHA rating system includes the sections of Life Cycle Costing, Socio-Economic Strategies, and Performance Metering and Monitoring. The various sections of GRIHA rating and potential areas for BIPV interventions are briefed in **Fig. 2.1**.

Fig. 2.1 Pie chart representing different shares for GRIHA rating in percentage and potential share for BIPV interventions. Source: [2].



2.2 Building Integrated Photovoltaic systems

If the necessity to improve the energetic performance of buildings induces the stakeholders of the construction sector to use solar systems, the rapidly growing construction market in India requires introducing new ideas and technologies. The installation of solar systems as building envelopes not only permits to transform buildings into solar power plants but also to integrate multifunctional properties of the construction system, replacement of building cladding materials and improving aesthetics considering the architectural image. The integration of solar energy systems in the buildings is well recognised with the acronym BIPV (Building Integrated Photovoltaic) as defined within the solar community. For example, now the BIPV products are available in different colours and sizes [7]. The reported market overview for state-of-the-art coloured BIPV products clearly reveals that, for all parts of a BIPV module, there are technical solutions available for colouring and customisation. Pilot projects utilising coloured BIPV products have been built in numerous (mainly European) cities, clearly demonstrating the maturity of these solutions. Besides the colour perception of the BIPV elements under solar irradiation, which is essential for the acceptance of the exterior appearance of a building, also the transparency and inside visual comfort of BIPV sells itself as essential window and façade elements for the users [8].

Since the building envelope normally cannot be produced in one piece, it is necessary to break it down into individual parts. For many years, the BIPV community did not reach a consensus about a reference categorisation of BIPV applications in the building skin. In this chapter, the definition of BIPV is provided on the basis of the specifics promoted by the IEA PVPS Task 15 [9]. The categorisation is based on three levels that include the i) application category, ii) system, and iii) cladding properties.

A definition of BIPV

IEC 63092-1:2020 [10] specifies BIPV module requirements and applies to photovoltaic modules used as building products. It focuses on the properties of these photovoltaic modules relevant to basic building requirements and the applicable electro-technical requirements. This document addresses requirements on the BIPV modules in the specific ways they are intended to be mounted but not the mounting structure itself, which is within the scope of IEC 63092-2. This document is based on EN 50583-1 [11]. The basic requirements for construction works are:

- Mechanical resistance and stability
- Safety in the case of fire
- Hygiene, health and the environment
- Safety and accessibility in use
- Protection against noise
- Energy economy and heat retention
- Sustainable use of natural resources

As already mentioned, the BIPV module is a prerequisite for the integrity of the building's functionality. If the integrated PV module is dismounted (in the case of structurally bonded modules, dismounting includes the adjacent construction product), the PV module would have to be replaced by an appropriate construction product. Inherent electro-technical properties of PV alone do not qualify PV modules as to be building-integrated.

Referring to the above-mentioned references, a definition of a BIPV module is exposed [12]:

A BIPV module is a PV module and a construction product together, designed to be a component of the building. A BIPV product is the smallest (electrically and mechanically) non-divisible photovoltaic unit in a BIPV system that retains building-related functionality. If the BIPV product is dismounted, it would have to be replaced by an appropriate construction product.

A BIPV system is a photovoltaic system in which the PV modules satisfy the definition above for BIPV products. It includes the electrical components needed to connect the PV modules to external AC or DC circuits and the mechanical mounting systems needed to integrate the BIPV products into the building.

Application categories

As mentioned in the previous paragraphs, the draft of the standard IEC 63092 [10] classified the BIPV applications into five main categories listed as "Application Categories" **(Tab. 2.1)**. It is applicable to different types of BIPV modules, and it is a classification according to the type of integration, slope and accessibility criteria, in particular:

- Integrated into the building envelope: yes/no
- Accessible from within the building: yes/no
- Sloped: yes/no

"Not accessible from within the building" means that another construction product still provides protection against mechanical impact within the building, even if the PV module has been damaged or removed. These categories are developed considering glass as a main substrate and material of the BIPV module retaining most of the mechanical properties.

System Categories

The classes of building skin systems can be identified as specialised construction units, and the categorisation is based on the main technological systems available for building envelopes. In conventional constructions, the definition of the main building skin construction systems can be grouped in:

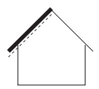
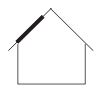
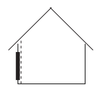
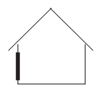
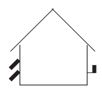
- *Roof*: A roof, in a traditional building construction with a top distinguishable by the facade, is the top covering providing protection and separating indoor and outdoor environments (application categories A and B).
- *Façade*: A façade, in a traditional building construction with parietal walls distinguishable by the roof, is the vertical (or tilted) exterior surface, which is the architectural showcase and separates indoor and outdoor environments. (Application categories C and D).
- *External integrated device*: Elements and systems of the building skin which are in contact only with the outdoor environment (application category E).

These groups can be categorised in sub-systems as shown in the following figures **Fig. 2.2** [9].

A specific definition of the sub-systems based on the IEA PVPS T15 [9] is presented below:

- *Discontinuous roof*: A "discontinuous roof" is typically a pitched/sloped opaque envelope part consisting of small elements (tiles, slates, shingles, etc.) with the primary function of water drainage. It is the part of the building envelope, where the PV transfer had its first successes due to the advantages of optimal orientation of pitches and the simplicity of installation. BIPV is typically part of the discrete elements composing the roof tiling, which form part of the roofing layer.
- *Continuous roof*: A "continuous roof", a flat or curved roof, is characterised by a large uninterrupted layer with the primary function of being water-resistant. Usually, membranes are used as a water barrier. In the first applications in time, the PV was mainly placed on top of the roof (BAPV). Lightweight and self-bearing systems represent the second generation of PV applications (BIPV). Flexible membranes, solar flooring and other solutions can be used for integrating PV as a multifunctional part of the building envelope.
- *Skylight*: These are light-transmitting building elements that cover all or a part of the roof. They are typically (semi)transparent for daylighting purposes, with additional thermal, acoustic and/or waterproofing functions when protecting an indoor environment. Alternatively, they serve mainly as a shelter if protecting outdoor (non-heated) areas (atriums). They can be fixed or openable, and retractable. PV is typically part of the glazed layer, applying both crystalline or thin-film PV technologies, and with various possibilities for transparency degrees and visual appearance.
- *Curtain wall*: It is an external and continuous building skin fenestration system, totally or partially glazed, composed of panels supported by a substructure in which the outer components are non-structural. A curtain wall refers to its construction, since façade is hanging (just as a curtain) from the top perimeter of the building and is locally fixed to resist air and water infiltration, and is typically designed with extruded aluminium frames (but also steel, wood, etc.) filled with glass panes. The façade should satisfy multiple requirements, such as a load-bearing function, acoustic and thermal insulation, light transmission, waterproofing, etc. E.g., in the configuration of "warm façade" it directly divides, as a skin layer, outdoor and indoor environments. It can be realised according to different construction systems such as stick-system, unitised curtain wall, Structural Sealant Glazing (SSG), point-fixed or suspended façade. In their most basic form, they are windows, while in more complicated forms, they can be used to realise complex skin façades. PV is typically part of the outer cladding layer, in the form of glass-glass elements, with crystalline or thin-film technologies and various transparency

Tab. 2.1 List of Application Categories. Source: IEA.

Category A:	Sloping, roof-integrated, not accessible from within the building The BIPV modules are installed at a tilt angle between 0° and 75° from the horizontal plane [0°, 75°], with another building product installed underneath	
Category B:	Sloping, roof-integrated, accessible from within the building The BIPV modules are installed at a til angle between 0° and 75° from the horizontal plane [0°, 75°]	
Category C:	Non-sloping (vertically) envelope-integrated, not accessible from within the building The BIPV modules are installed at a tilt angle between 75° and 90° from the horizontal plane [75°, 90°], with another building product installed behind.	
Category D:	Non-sloping (vertically), envelope-integrated, accessible from within the building The BIPV modules are installed at a tilt angle between 75° and 90° from the horizontal plane [75°, 90°]	
Category E:	Externally-integrated, accessible or not accessible from within the building The BIPV modules are installed to from an additional functional layer that provides a building requirement. E.g. balcony balustrades, shutters, awnings, louvres, brise soleil, etc.	

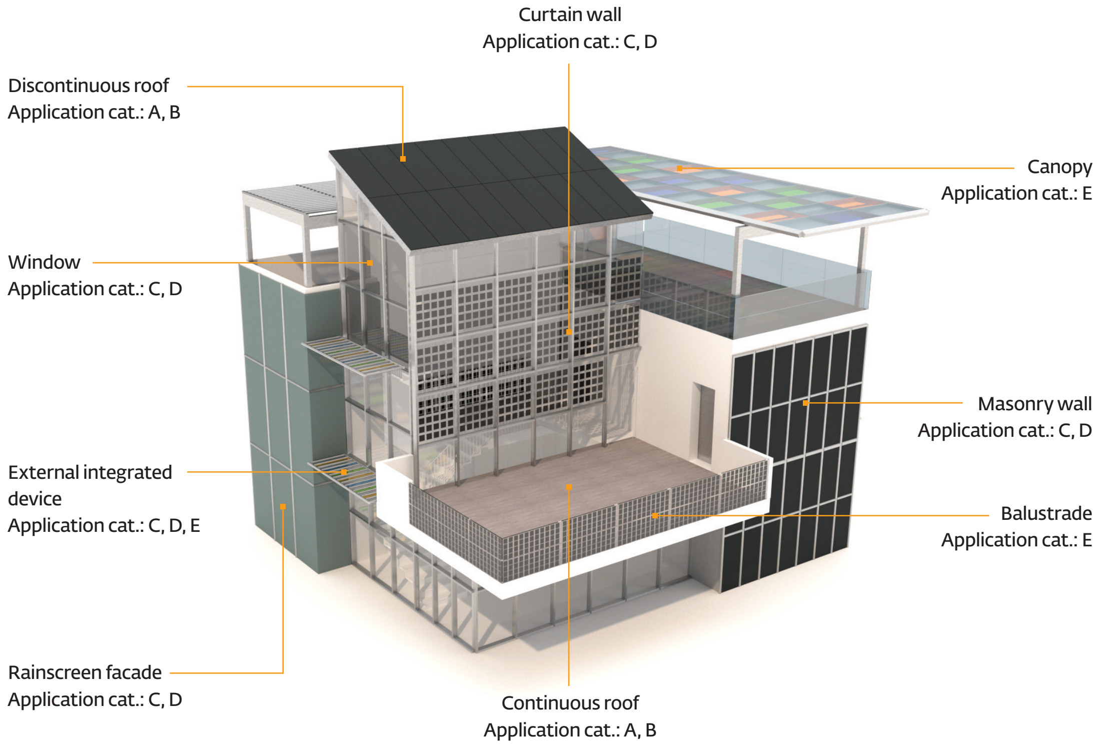


Fig. 2.2 System categories. Source: SUPSI.

- degrees and visual appearance possibilities. Usually, the glass is an IGU (double or triple glazing) to ensure adequate thermal and acoustic insulation.
- *Rainscreen*: Well known as a "cold" or ventilated façade, it consists of a load-bearing substructure, an air gap and a cladding. In summer, heat from the sun is dissipated, thanks to the cavity that usually is naturally ventilated through bottom and top openings. A rainscreen is ideal for enhancing rear ventilation. It is typically categorised as "vented" with openings at the bottom; "ventilated" openings at both the bottom and top; and "pressure equalised" rainscreen with compartmentalisation in the air cavity. Many construction models and technological solutions are available on the market, also with various joints and fixing options. Usually, PV elements are integrated similarly to opaque, non-active building cladding panels and can assume many aesthetic configurations, especially through glass customisation (colours, textures, sizes, etc.).
- *Double skin façade*: It consists of two layers, usually two glazing elements wherein air flows through the intermediate cavity. This space (which can vary from 20 cm to a few meters) acts as insulation against extreme temperatures, winds, and sound, improving the building's thermal efficiency for both high and low temperatures. PV is applied similarly to a curtain wall even though the outer façade, in this case, does not require thermal insulation. Thus, it is often a glass laminate rather than an insulated glazing unit (IGU).
- *Window*: A window is a glazed wall opening to admit light and often air into the structure and to allow outside views. Windows, as a very ancient invention probably coincident with the development of fixed and enclosed constructions, are also strongly related with the building architecture, the space design, climatic conditions, functions, technologies and performance, etc. PV can be integrated into conventional PV glazing or also into some innovative applications.
- *Masonry wall*: A "barrier wall" or "mass wall" is an exterior wall assembly of bricks, stones or concrete that relies principally upon the weather-tight integrity of the outermost exterior wall surfaces and construction joints to resist bulk rainwater penetration and/or moisture ingress (e.g. precast concrete walls, exterior insulation and finish systems EIFS, etc.) or upon a combination of wall thickness, storage capacity, and (in masonry construction) bond intimacy between masonry units and mortar to effectively resist bulk rainwater penetration.
- *External integrated device*: These include 1) Transparent or opaque multi-functional and photovoltaic solar shading devices (Louvres or embedded venetian blinds) for façades or balustrades with the role of "fall protection" that are necessary for the safety of the building (e.g., in balconies, loggias, parapets);2) Transparent or opaque shading devices for roofs aimed to select the solar radiation; 3) Integrated canopies, greenhouses and veranda.
- *Canopy*: A canopy is an unenclosed roof or a structure over which a covering is attached, providing shade or shelter from weather conditions. Such canopies are supported by the building to which they are attached or also by a ground-mounting or stand-alone structure, such as a fabric-covered gazebo.

BIPV cladding properties

Cladding is referred to the external part of the technological system layering (e.g., façade cladding or roof tiling) together with the associated technological requirements (e.g., building covering, weather protection, safety, etc.). Today, BIPV claddings, namely the BIPV modules, can be tailored for almost every kind of building envelope resulting in a performing and high aesthetic solution. The customisation aspect includes colour, dimension, shape, thermal properties, material, etc. A categorisation of BIPV cladding, based on their properties and application, as defined in the framework of report D1.3 of the project H2020 BIPVBOOST project [13] is reported in Tab. 2.2. It offers to architects, building owners and other stakeholders of the BIPV value chain an overview of the possibilities offered by BIPV products:

Tab. 2.2 BIPV cladding properties. Source: IEA.

CLADDING	DESCRIPTION	SOURCE
MATERIAL	It represents the main material/s in which the solar cells are integrated or encapsulated in order to form the end BIPV product. Today, the most common material is glass, used as module backsheet and/or frontsheet. Glazed solution is suitable for semi-transparent and opaque solutions. Other supporting materials adopted for BIPV installations include polymer, metal, and cement-based materials. The features of the material establish the thermal, architectural and technical properties of the building envelope.	BIPVBOOST [13]
TRANSPARENCY	It permits to distinguish semi-transparent and opaque solutions. Semi-transparent solutions are suitable for curtain walls, double skin façades, warm façades, skylights, canopies, etc. The transparency value of BIPV modules allows architects and designers to increase the building's user comfort and energetic performance. The assessment of daylighting, glare and view out are additional parameters that can be set by adjusting the transparency performance of semi-transparent surfaces. Opaque solutions do not permit the light to pass through the building envelope. These solutions are suitable for rainscreen, prefab roof/façade, railings, louvres, curtain wall, flat or pitched roof solutions.	BIPVBOOST [13] IEA PVPS Task15 [9]
THERMAL INSULATION	It is referred to the module's thermal transmittance (U value). The thermal protection of the building is given by the materials that form the building skin. The minimum value required to overcome the energetic standard depends on the local regulations. The following solutions give the thermal insulation for the claddings: • Insulated glazed unit: Glazed solution normally used when thermal protection between two spaces is required (insulated glass unit, curtain walls or skylights, etc.); • Prefab solution: Composite solution where the cladding is one single element composed of a front-sheet, photovoltaic layer and a substrate. The front-sheet could be either glazed or not glazed. The substrate could be composed by different functional materials such as for thermal/acoustic or fire protective layers.	BIPVBOOST [13] IEA PVPS Task15 [9]
COLOURING	This framework represents one of the possible ways to customise and boost architecture. Today, several manufacturers offer coloured solutions, and the implementation of coloured modules is growing fast. In such a way, for example, PV cells can be camouflaged behind coloured patterns that completely dissimulate the original visuality of the PV cells. A shortlist of the colouring possibilities available in the today's market is presented below: • Products with coloured/patterned interlayers and/or with special solar filters • Products with coloured and/or semi-transparent PV-active layers (thin film, OPV) • Products with coloured polymer films (encapsulant, backsheet) • Products with coated, printed, specially finished or coloured front glass covers • Products with coloured anti-reflective coatings on solar cells (c-Si)	BIPV Status Report 2020 [7] IEA PVPS Task15 [8]
SIZE	The size parameter are distinguished as i) Large modules, when they exceed 2.6 m in any dimension or 2.1 m in both dimensions, ii) Less than 0.9 m in both dimensions for shingle, iii) Regular modules, when they do not fall under the categories of large or shingle [14].	IEA PVPS Task15 [9]

2.3 BIPV potential for buildings

To optimise the energy production from solar panels, one of the most investigated aspects is the relation between solar yield with orientation and inclination. The optimal inclination to exploit the maximum solar irradiation is mainly a matter of solar geometry; i.e., it depends on the location's latitude. However, for BIPV, the orientation possibilities need to be defined from the building design stage itself.

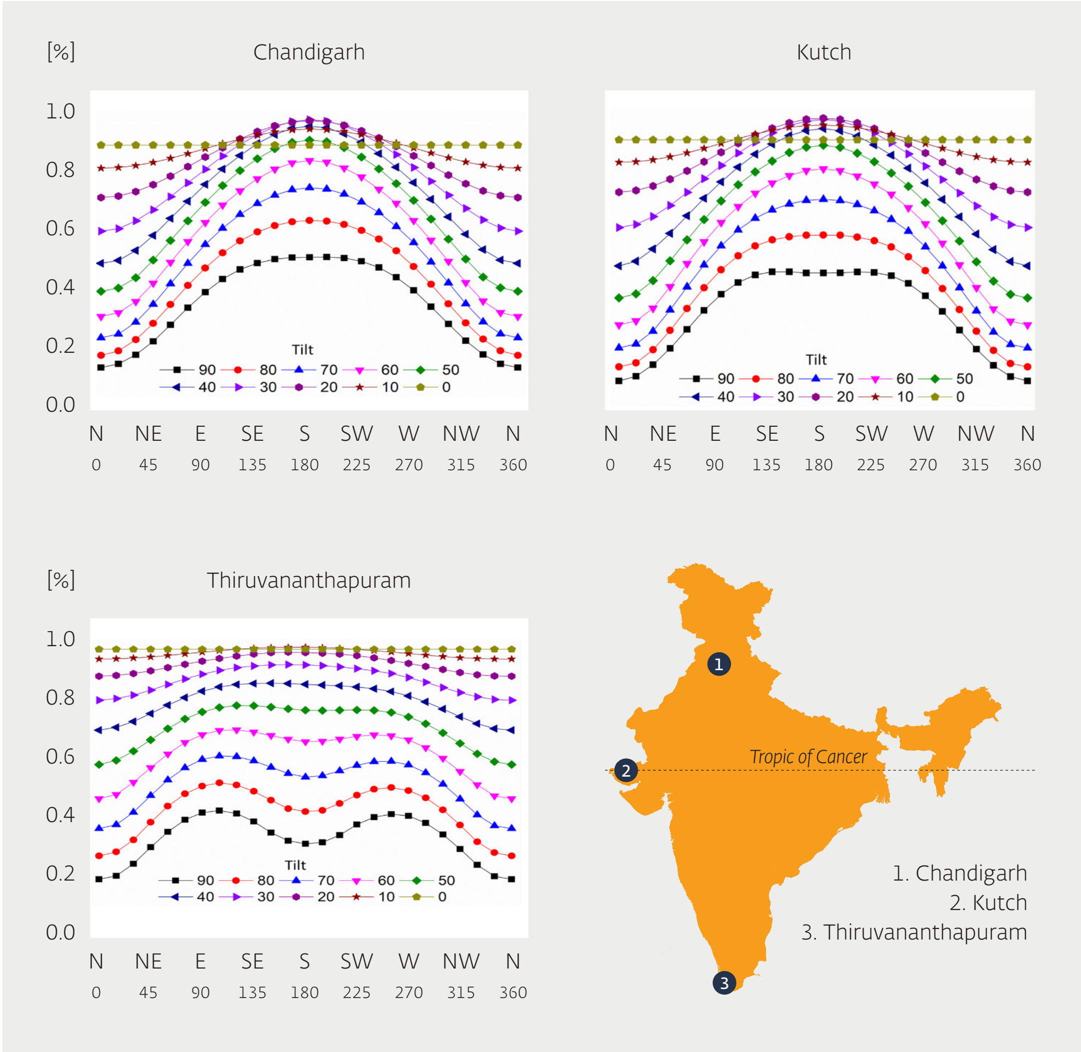
India has an extend of land from 8°4' to 37°6' North latitude and 68°7' to 97°25' East compiling 29 states and 6 union territories. In India, the Tropic of Cancer passes through eight states: Gujarat, Rajasthan, Madhya Pradesh, Chhattisgarh, Jharkhand, West Bengal, Tripura and Mizoram. This specific feature of India does so that for locations to the north of Tropic of Cancer, solar radiations at peak time occur to be from South directions only for all the seasons. Moving from south to north of India, the optimal PV tilt angle for maximum energy generation, increases due to the decreased solar height. However, for the evaluation of BIPV potential based on application category in the Indian scenario, we need to consider the solar exploitation potential for different PV orientation and tilt angles. Herein, we have considered three locations in India for the study: 1. Thiruvananthapuram (Latitude 8.470865°; Longitude 76.991872°; Annual global irradiation on the horizontal plane 1945.3 kWh/m²); 2. Kutch ((Latitude 23.527348°; Longitude 70.785662°; Annual global irradiation 2050.5 kWh/m²); 3. Chandigarh (Latitude 30.7334421°; Longitude 76.7797143°; Annual global irradiation 1788.5 kWh/m²) (Irradiation data acquired from PV*SOL online tool). The locations are selected for the general solar pattern typology in India; Thiruvananthapuram for location south of Tropic of Cancer, Kutch for location passing through Tropic of Cancer, and Chandigarh for location north to Tropic of Cancer. The distinction in solar path of the three places is evident from the figure that for the southern location (Thiruvananthapuram) solar irradiation is coming from the North direction alone for more than one-third of the year, which will be reduced when moving towards north. The pattern will be evident up to the places of Tropic of Cancer (like Kutch), further moving towards north (like Chandigarh) will reduce the share of northern irradiation, particularly at the solar peak of a day.

To unlock the solar energy integration in the built environment, the assessment of the BIPV potential for existing urban areas represents a preliminary fundamental step. In fact, by knowing the BIPV potential, urban decision-makers can support the integration of PV in the urban environment with appropriate policies to achieve energy transition goals. Specifically, to assess the urban BIPV potential of façades, not only solar radiation analysis is required but also the identification of construction façade characteristics, which significantly affect the real BIPV exploitability. Many current urban BIPV façade cadastres generally do not consider specific building characteristics since the majority of them are based on 3D city models (e.g. LOD200-schematic design), meaning that the influence of architectural elements (such as windows, balconies, etc.) is not evaluated. Therefore, it is crucial to have a calculation method capable of matching existing solar radiation analysis with architectural characteristics of façades, through building typological indicators, in order to better estimate the urban BIPV potential, especially for façades, to improve the current estimations and create the framework to properly evaluate BIPV potential from the early design phases [15].

The following paragraphs present an in-depth analysis of the sun position in India and the related solar irradiation of the building envelope.
The solar potential study involved the data acquisition of energy generation from PV at the intended locations for different tilt and orientation of PV using PV*SOL online tool (Assumptions: Calculated for roof-mounted 300 Wp Si monocrystalline PV modules (18.1% efficiency) with zero considerations of diffuse light, shadowing and soiling loss). The data generated are used for a comparative study of the optimum tilt and orientation of PV at the specific locations, thus normalising the factor of annual global irradiance and the assumptions taken. The PV Energy Factor (ratio of energy that can be generated yearly for the specific tilt and orientation to the maximum possible energy generated at the optimum tilt and orientation for the same system at a specific location) of the location is plotted for the three locations with different tilt and orientations.
The optimum orientation is south for India, the tilt being higher in northern regions, as shown in the **Fig. 2.3** for Kutch and Chandigarh. This is due to the lower solar azimuth angle for northern regions compared to south. The optimum angle for Thiruvananthapuram, Kutch and Chandigarh is 8˚, 23˚ and 26˚ respectively.

The condition of southern states is thus more suitable for collecting irradiation with horizontally flat or small pitched PV systems (<10˚). Compared to Kutch and Chandigarh, the south state, Thiruvananthapuram shows a peculiar pattern of maximum energy factor around E-SE and W-SW orientations for vertically tilted PV systems. The formation of this pattern is due to the availability of irradiation from north for a considerable number of days in the southern locations. The pattern tends to diminish by decreasing the PV tilt. Also, the influence of irradiation from the north will reduce much when we travel from south to north of India, diminishing the pattern, thus the placement of vertical PV systems seems liberal in the northern region. As shown in the figure, Kutch and Chandigarh can utilise E-S-W orientations for vertical PV systems, offering a liberal vertical PV positioning.

Fig. 2.3 i) Top left: PV Energy Factor for Trivandrum; ii) Top right: PV Energy Factor for Kutch; iii) Bottom left: PV Energy Factor for Chandigarh. iv) Bottom right: Marking of selected locations in India. Source: NIIST.



For designing BIPV/BAPV integration in new or existing buildings, the necessity of mapping and valuing the solar potential of that building is crucial for efficient energy and economic optimisations. The BIPV potential of a building is associated with the factors like location, orientation and tilt of potential building surfaces, and other external factors (not considered here) like shading loss, soiling loss, hail loss, clouding loss, atmospheric pollution loss, etc. Herein, as an example, the representation for BIPV potential score (PV energy factor converted as score in 100 for easy adoption) is shown Fig. 2.4 indicatively for the three selected locations, and applicable for categories:

1. Sloping roof integrated (category A and B): Discontinuous and continuous roof, skylight, canopy. The BIPV score has been calculated with a minimum tilt angle of 0°.
2. Sloping roof integrated (category A and B): Discontinuous and continuous roof, skylight, canopy. The BIPV score has been calculated with a maximum tilt angle of 15°.
3. External integrated (category E): External integrated device and canopy. The BIPV score has been calculated with a tilt angle of 75°;
4. Non-sloping (vertically) envelope-integrated (category C and D): Rainscreen, curtain wall, double skin, window and masonry wall. The BIPV score has been calculated with a minimum tilt angle of 75°.
5. Non-sloping (vertically) envelope-integrated (category C and D): Rainscreen, curtain wall, double skin, window and masonry wall. The BIPV score has been calculated with a maximum tilt angle of 90° (refer BIPV application category).

In conclusion, the mapping of solar potential score for buildings (including the external losses) helps in identifying the utilisable surfaces and solutions for BIPV/BAPV integration for efficient investment. For new buildings, a score mapping according to the building design (including shade and utilisable surface analysis) can support the generation and modification of BIPV innovative designs for better energy and economic optimisation with efficient material utilisations.

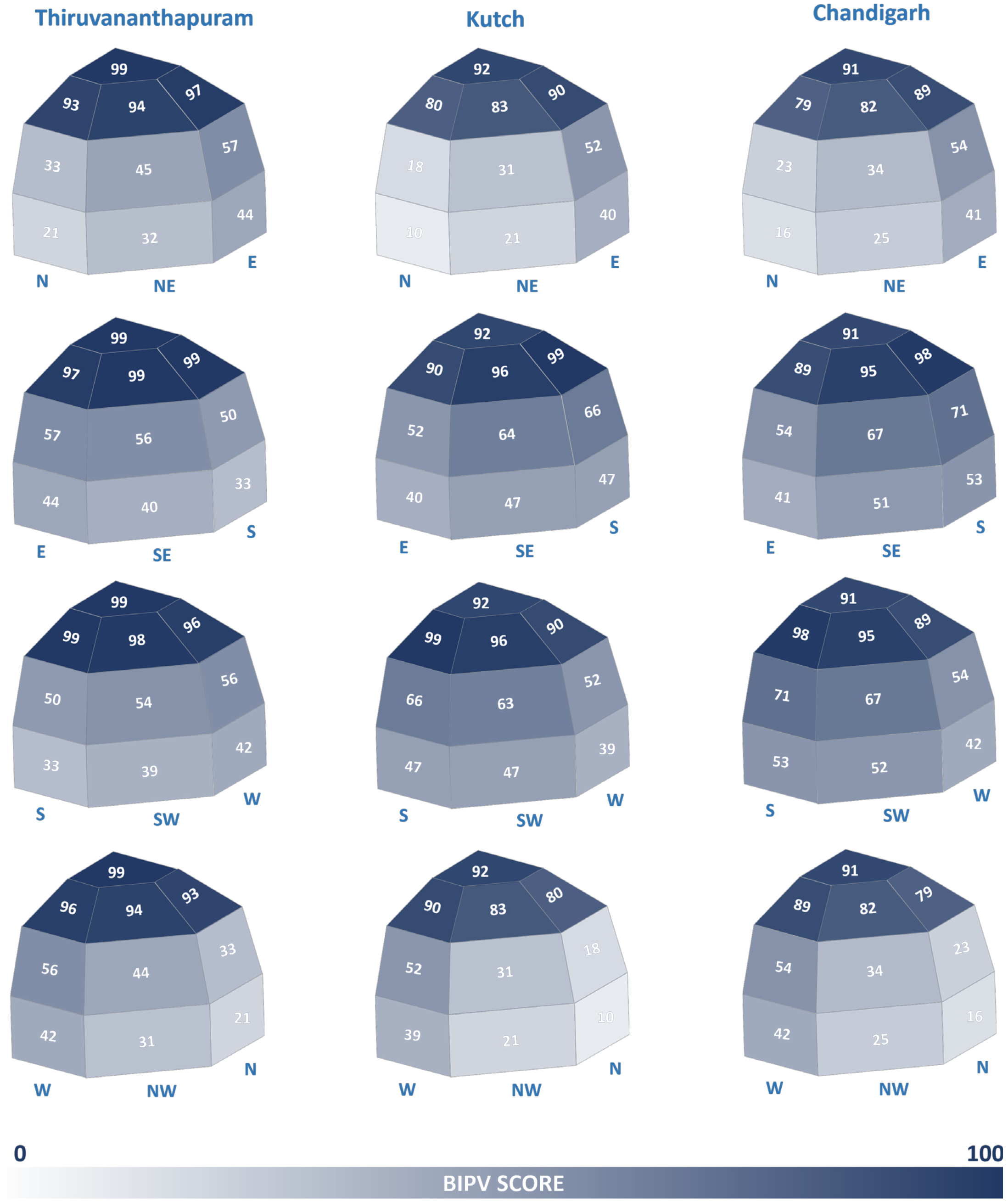


Fig. 2.4 BIPV Score: PV energy factor converted as score in 100 for easy adoption. Source: NIIST.

References

[1] KPMG, "Indian real estate and construction : Consolidating for growth," Natl. Real Estate Dev. Counc., no. September, 2018, [Online]. Available: https://assets.kpmg.com/content/dam/kpmg/in/pdf/2018/09/real-estate-construction-disruption.pdf.

[2] IBEF, "Indian Real Estate Industry," 2021. https://www.ibef.org/industry/real-estate-india.aspx.

[3] "International Energy Agency and the United Nations Environment Programme (2018): 2018 Global Status Report: towards a zero- emission, efficient and resilient buildings and construction sector," p. 325, 2018, [Online]. Available: http://www.ren21.net/wp-content/uploads/2018/06/17-8652_GSR2018_FullReport_web_final_.pdf.

[4] Dodge Construction Network, "World Green Building Trends 2021." 2021.

[5] Bureau of Energy Efficiency (BEE), Eco-Niwas Samhita 2018 (Energy Conservation Building Code for Residential Buildings), Part I: Building Envelope. December, 2018.

[6] GRIHA Council, "GRIHA 2019," vol. 1, no. Third Edition 2021, pp. 1–137, 2021, [Online]. Available: https://www.grihaindia.org/.

[7] P. Corti, P. Bonomo, F. Frontini, P. Macé, and E. Bosch, "Building Integrated Photovoltaics : A practical handbook for solar buildings' stakeholders Status Report," 2020. [Online]. Available: www.solarchitecture.ch,.

[8] G. Eder et al., "Coloured BIPV Market, research and development IEA PVPS Task 15, Report IEA-PVPS T15-07: 2019," p. 57, 2019, [Online]. Available: http://iea-pvps.org/index.php?id=task15.

[9] P. Bonomo and G. Eder, Categorization of BIPV applications. 2021.

[10] "IEC 63092-1:2020. Photovoltaic in buildings - Part 1: Requirements for building-integrated photovoltaic modules." .

[11] "EN 50583-1. Photovoltaics in building - Part 1: BIPV modules." .

[12] K. Berger et al., "International definitions of BIPV," Rep. IEA-PVPS T9-18 2018, p. 32, 2018, [Online]. Available: https://iea-pvps.org/wp-content/uploads/2020/02/IEA-PVPS_Task_15_Report_C0_International_definitions_of_BIPV_hrw_180823.pdf.

[13] SUPSI et al., "Collection of building typologies and identification of possibilities with optimal market share," BIPVBOOST, 2019.

[14] "IEC, IEC Committee Draft 61215-1 ED2 Terrestrial photovoltaic modules – Design qualification and type approval – Part 1: Test requirements, 2020." .

[15] E. Saretta, P. Bonomo, and F. Frontini, "A calculation method for the BIPV potential of Swiss façades at LOD2.5 in urban areas: A case from Ticino region," Sol. Energy, vol. 195, no. November 2019, pp. 150–165, 2020, doi: 10.1016/j.solener.2019.11.062.

Acknowledgements

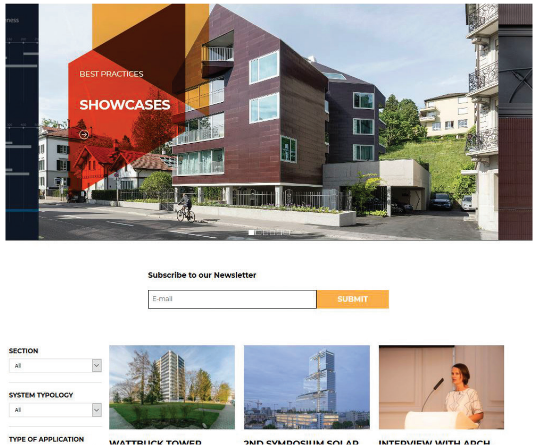
SUPSI would like to acknowledge the Zurich University of Applied Sciences as Leading House for the bilateral research collaboration. SUPSI also acknowledges the Director of the Institute of Applied Sustainability to the Built Environment (ISAAC), Dr. R. Rudel, and the BIPV team of SUPSI.

CSIR-NIIST would like to acknowledge The Department of Science and Technology (DST), Ministry of Science and Technology, India for the funding grants provided through DST-INSPIRE Faculty Scheme. CSIR-NIIST also acknowledge the Director of the Institute, Dr. A. Ajayaghosh, for the constant support throughout the Indo-Swiss "SOLID BIPV-Solar constructions in India: Needs and innovation challenges for BIPV implementation" project and successful completion of the present report.

SUPSI and CSIR-NIIST would like to recognize the valuable contribution from the industrial partners as financial and intellectual support, along with their co-operation in the report chronicling, in particular: Onyx Solar, U-Solar, TopSun, Anu Solar Power and Sunsenz who kindly provided information for the analysis of study cases.

Disclaimer

Info at
Swiss BIPV Competence Centre Institute for Applied Sustainability to the Built Environment
Campus Mendrisio
Via Flora Ruchat-Roncati 15
CH-6850 Mendrisio
T +41 (0)58 666 63 51
F +41 (0)58 666 63 49
pierluigi.bonomo@supsi.ch



The website www.solarchitecture.ch is one of the communication means of the Swiss BIPV Competence Centre.
Here you find essential information concerning pv technology integration in buildings and different projects realized both in Switzerland and abroad. Moreover, a large database of BIPV modules and fastening systems collecting the main product's information in a datasheet is available. The website is an active interface opened towards different stakeholders thanks to the possibility to upload and store your BIPV examples (architects, installers, owners, etc.), products (manufacturers, suppliers, installers, etc.) as well as to the technological/client support through the contact info@bipv.ch.

Impressum

Editor
SUPSI, University of Applied Sciences and Arts of Southern Switzerland

Authors
Paolo Corti
Pierluigi Bonomo
SUPSI, University of Applied Sciences and Arts of Southern Switzerland
Swiss BIPV Competence Centre, Institute for Applied Sustainability to the Built Environment

Animesh M Ramachandran
Adersh Asok
Photosciences and Photonics Section
CSIR-National Institute for Interdisciplinary Science and Technology

Book features
Format
175× 230 mm
21 pages