Chapter 18
Building-Integrated Photovoltaics (BIPV) in India: A Framework for TRIZ-Based Parametric Design

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18.1 Introduction

> We humans are not facing a shortage of energy. We are facing a technical challenge in capturing it and delivering it to consumers—Jostein Eikeland

In today's world, energy is the primary driver of all economic activity and is essential for developmental activities. Thus, it is essential to evaluate and conserve available resources, to consolidate the economic and environmental feasibility of untapped renewable sources of energy (Traversa and Idriss 2012). All of these technologies should be novel, efficient, renewable, safe, user friendly and environmentally sustainable (Traversa and Idriss 2012). Fulfilling power generation has become a significant concern since the rate of power production does not match the growing power demand thus, leading to a severe energy crisis. This increasing demand gives much stress over the existing power generating sources. Non-renewable resources of energy fail to cope with the ever-increasing needs; further, these resources result in harmful emissions making them unclean energy resource, thus leaving an adverse impact on the environment (Leonzio 2017). To cope with the rising power demand there is a need to switch from conventional

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sources of energy to a renewable and sustainable source of energy. To meet the target, a large amount of energy is required than what is currently generated. Thus, it is essential to switch to renewable energy resources.

Renewable energy is in demand as it has the potential to mitigate environmental emissions and improve public health. Renewable Energy Sources can reuse and produce energy such as solar, wind, geothermal energy and biomass (Squalli 2017). To make the future energy-sufficient, new emerging ideas must be incorporated that will create a primarily new world, depicted by the greater use of renewable energy resources like Solar power (Sindhu et al. 2017). Today's technology-driven urban lifestyle stress on more electricity consumption. Due to the use of more electricity-consuming appliances and machines, the electricity demand will double by 2060 (World Energy Council 2016). Therefore, requirements for a low carbon future incentivise us to make significant changes in the building models or face downfall.

Photovoltaic systems are characterised by Active solar technologies. This technology converts energy from sunlight directly into electricity, using large arrays of solar panels, which can be integrated into a building to produce power (Wald and Rodeck 2012).

The amount of sunlight that gets absorbed by the earth in one minute can power an entire planet for a year. The technology needed to harness this power has been around for over sixty years but has not always been aesthetically applied. Now, with recent advances in solar technology, solar tiles can be seamlessly installed into the buildings. This integration of photovoltaic cells on the building as primary components of the building is called Building-Integrated Photovoltaics (BIPV). In this system, the PV panels are integrated into building components such as walls, roofs or windows to capture the maximum amount of sunlight and heat (Baljit et al. 2016).

18.2 Literature Review

BIPV is a kind of building system and the workpiece of an architect. BIPV modules may differ depending upon their applications. Different types of modules are (1) Classic (framed), (2) Thin Film (3) Roof-tiles with solar cells, (4) Transparent Monocrystalline, (5) Coloured solar cells, (6) Semi-transparent Micro-Perforated, (7) Amorphous cells. These modules can be further customised based on module shapes, colour, Transparency, cell type, lamination size, lamination construction, module voltage, heat/noise isolation (Roberts 2009) (Table 18.1).

Solar energy is considered one of the cleanest sources of energy; however, there are a few drawbacks that should be carefully discerned. The manufacturing cost is high; also the high requirement of maintenance make it challenging to be used widely. Furthermore, this system can be influenced by weather. Cloud cover, rain, snow and hail storm may damage the system (QC Solar 2013). While the module size is limited, a very accurate shading analysis needs to be made before the system

Table 18.1 Comparison of different types of photovoltaic panels

Types of Cells → / Factors ↓	Monocrystalline	Polycrystalline	Thin Film
Cost	Rs. 45-50 /W	Rs. 37-48/W	Rs. 12-15/W
Output (250w)	1.5 m^2	2.2m^2	6m^2
Efficiency	14-19%	12-16.5%	4.7%
Availability	less	high	high
Performance Temp. Range	0-20°C	≥45°C	≥60°C

installation. Additionally, the analysis of light and shadow effects are very significant while designing a building, which is decided by the facade to a great extent. The BIPV junction boxes are often too big and glued on the backside of the panel, which spoils the magnificence of the whole building. This comes as a challenge to an architect, as there is a need to hide it (Prasad 2005).

18.2.1 Indian Scenario

India contributes is one of the highest consumers of primary energy demand and its economy would become five times its current size in 2040. India is on the path of becoming the most populous country by 2027 leaving behind China (World Energy Council 2016). Due to a high GDP growth rate, India emerges as a major driving force in global trends, with all modern fuels and technologies playing a part. India has stepped up the installation and use of solar energy by:- a) providing subsidies, b) focussing on expanding its markets with increased operational effciency, and c) deploying various government schemes and programs (World Energy Council 2016).

18.3 Methodology

A comparative analysis was done to understand the currently available technology of ‘building-Integrated Photovoltaics in India through a comprehensive literature review. Three buildings retrofitted with photovoltaics were studied namely—a residential building in Trivandrum, Kerala; Central Public Works Department in Dehradun; and National Institute of Advanced Studies, Bangalore. Subsequently, various building-design parameters were identified using TRIZ methodology to develop a framework for BIPV based parametric design. Using this framework, a preliminary 3D-building model was designed on Sketchup software which was later analysed for total power production. (TRIZ Method is a systematic approach to solve the challenging problems by an inventive method called '*Teoriya Resheniya Izobretatelskikh Zadach*' developed by 'Genrich Altshuller.) Later, a reference model was proposed illustrating the importance of BIPV based solar buildings as the primary power generating units of the solar city.

18.4 Results

Table 18.2 illustrates the various features of BIPV case studies (literature-based), which was carried out to understand the design and integration of photovoltaics in buildings. While Table 18.3 summarises, the results obtained from three primary case studies of buildings retrofitted with PV in different places.

Table 18.2 Examples of the usage of BIPV from literature

Project	Location	Capacity (MW)	Size	Year	Remarks
Longyangxia dam Solar park	Qinghai, China	850	27 km^2	2015	The total installed capacity shall be increased up to 77 GW in future
Harvard University	Cambridge, Massachusetts, U.S.A.	2.14		2003–2017	Various buildings in Harvard University has BIPV integration
Ludesch Town Hall	Ludesch, Bludenz, Austria	0.0198	204.2 m^2	2006	•Pitched roof •Solar-glass laininated-PV •17.5% transparency •Monocrystalline •Used as sun shade
Solar roof Speicher	Speicher, Switzerland	0.173	1100 m^2	2014	•Pitched roof •Sports center •Monocrystalline •East-west orientation •Opaque
The New York Stillwell Avenue Subway Station	Brooklyn, New York	250 annually	7,100 m^2	2004	•Glazed roof with PV panels •2,730 thin-film modules •Cover 15% of power

Table 18.3 A case study of photovoltaic powered building systems at different locations

Case study city	Location	Area (m^2)	Technology used	Energy produced	Energy savings
Dehradun	30.318°N 78.029°E State: Uttrakhand	900	Polycrystalline cells	12 KW	50% energy consumption rate
Trivandrum	8°28'N, 76°57'E State: Kerala	30	Polycrystalline cells	1 KW	90% energy consumption rate
Bangalore	13°01'N, 77° 33'E State: Karnataka	778	Polycrystalline cells	100 KW	50% energy consumption rate

Table 18.4 TRIZ based morphological analysis of different design ideas

Type	Monocrystalline ● (red)	Polycrystalline ● (green)	Thin Film	Transparent ● (blue)
Paint	Reflecting ● (red)	Absorbing ● (green)	Solar Dye ● (blue)	
Position	Roof	Wall ● (red)	Facade ● (blue)	Windows ● (green)
Cost	High ● (blue)	Affordable ● (red)	Low ● (green)	
Energy Efficiency	High ● (blue) ● (red)	Average ● (green)	Low	
Novel Technology	Sun tracking	Temperature tracking ● (red)	Self Cooling ● (green)	Still ● (blue)
	● (red) D1	● (green) D2	● (blue) D3	

Various design parameters were put together to come up with three innovative design ideas by group brainstorming. These design ideas were later formulated to the conceptual stage by TRIZ methodology (as shown in Table 18.4). Three building designs D1, D2 and D3 were created using the framework and compared against each other using the weighted mean method.

A 14-floor high-rise model was created based on the combination of best features of these three design ideas. The building was well integrated with photovoltaic panels on the dome, the exterior wall, and windows. The total amount of energy

Table 18.5 Energy calculation of the proposed building design model

Dome power yield *Design basis: dome radius = 12.5 m = $\left({}^1\!/_2\right) \times$ $(4 \times \pi \times R^2 \times 250 \div 2.2) \times (1/3) = 38$ kW	Panel power yield *Design basis: 250 W/2.2 m^2 = $(250 \div 2.2) \times$ $W \times L \times N = 68.2$ kW
Transparent panel power yield *Based on available PV cell output @ 125 W/m^2 = 52.5 kW	Cumulative power yield = 158.5 kW Energy units saved = 792 units (Considering 5 horns of effective sunlight) Greenhouse gas emissions saved = 5 tonnes/day

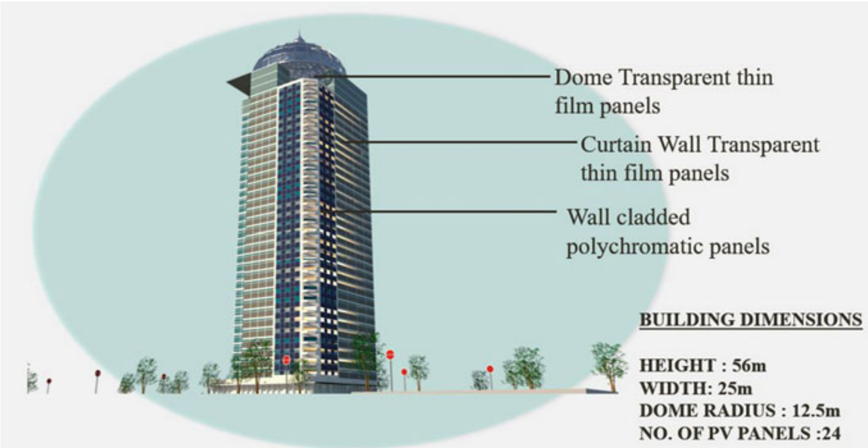

Fig. 18.1 Proposed design model for BIPV high-rise building

created from the photovoltaic panels was calculated (see Table 18.5). The total energy generated was 158.5 KW, which is enough to meet the power requirement of the building. Also, the building saved 5 Tonnes of greenhouse gases (GHG) emission per day (Fig. 18.1).

The proposed building model could work as a power production unit by giving back unused power to the grid, thus reducing the carbon emission level. The combination of these technologies with innovative design ideas would play a significant role in the development of solar-powered home; acting as the primary unit of solar cities. Finally, a reference model for solar city was proposed which would generate sufficient energy from the sun (Fig. 18.2).

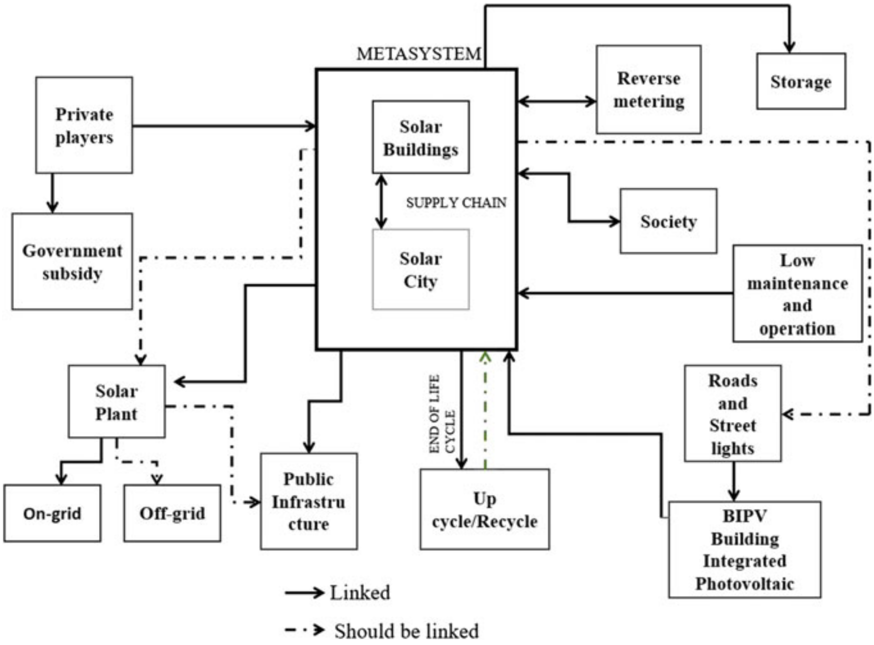

Fig. 18.2 Proposed reference model for the solar city based solar home

18.5 Discussion

It can be inferred from Table 18.2 that solar parks need a large area which makes them practically infeasible in congested urban areas such as those found in Indian cities. While as seen in the Harvard university example, BIPV integration in an educational campus would be far more rewarding in terms of energy generation if done in a coordinated and planned way. Moreover, Ludesch Townhall uses its roof and sun-shades to integrate monocrystalline laminated PV with 17% transparency, thus making a case for public buildings to adopt BIPV in a big way. The New York Stillwell Avenue subway station uses thin-film modules in an innovative manner while reducing the efficiency of the cells as a trade-off.

In Table 18.3, It can be seen that most Indian buildings are retrofits (and use polycrystalline cells), highlighting the fact that the photovoltaic integration was not part of the original building plan, but an afterthought. Hence, we need to integrate consideration of BIPV integration at the early design stages of building design.

In Table 18.4, the various parameters identified by the TRIZ method was listed as (a) type of solar cells; (b) Type of paint (c) Position of Photovoltaic Integration; (d) cost of the technology; (e) Energy efficiency and (f) novel technologies used (e.g. Movement/tracking type and self-cooling, etc.). A combination of the three designs D1, D2, and D3 combined with creative planning helps authors come up with a model building which performs quite well in terms of energy efficiency as seen in Table 18.5. While this preliminary building model is only the starting point as a huge number of designs can be created using this TRIZ based framework which can be populated along the rows and columns over time. The quality of design data assessed would directly impact the quality of designs generated.

Finally, a meta-system of solar buildings acting as a basic unit of solar cities was defined and proposed. It can be inferred by Fig. 18.2 that storage and disposal (End-of-Life) would be major challenges in the coming future to solar cities. While low maintenance and operation costs are factors that are still far from achieved in the Indian context. Unused power can be transferred to the grid and consumers can earn monetary benefits in terms of power-units. A capacity-building program addressing the technical repair capability of service providers in Tier 2 and Tier 3 cities would be needed. This proposed city, would not only generate power for itself but will also provide energy for energy-starved rural areas. A synergy between government and private players needs to be attained to manufacture, install, operate, maintain and recycle photovoltaics on an urban scale.

18.6 Conclusion

The results of integrating solar panels in the building would be the generation of clean solar energy which would reduce the stress on non-renewable and polluting sources of energy. Commercial Buildings, institutional buildings, and modern-day residences can become Independent power-producers. Various designs can be created using the proposed TRIZ-based parametric design framework that suits both building aesthetics and energy efficiency. It was found that buildings designed utilising the proposed framework could significantly reduce the overall energy load on the power grid and become energy neutral or energy positive in the true sense. Solar power generation can significantly advance buildings' sustainability through improved energy performance and renewable energy generation. Moreover, the upscaled solar building model can serve as a nucleus for providing impetus to smart cities program of the government of India. This methodological analysis shows that solar power generation can significantly advance buildings' sustainability through improved energy performance and renewable energy generation. The proposed reference model for a solar city based on solar buildings as the primary power generating unit needs to be studied further for its impact on the environmental sustainability of the building sector.

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