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Solar PV Facade for High-rise Buildings in Mumbai

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Abstract

India is blessed with abundant sunshine & solar energy is getting the importance it deserves in recent times. Distributed generation is a key aspect of Solar PV in India. Accordingly, high-rise buildings in urban areas which are major consumers of energy need to be utilised as sites for Solar PV. Though roof-top Solar PV has been getting due attention, facades of high-rise buildings also offer a great opportunity for Solar PV. This research paper aims to assess the potential for monetary savings & reduction in GHG emissions using Solar PV Facades in high-rise buildings in Mumbai, India. The concept can also be applied to high-rise buildings in other parts of India. The payback period for the same is also very attractive in a city like Mumbai . There is a need to include Solar PV Facades from the concept stage in high-rise buildings to ensure proper integration & minimum cost. Thin Film technology is a good choice for Solar PV Facades in India as demonstrated from the results with CdTe modules in this paper. Saving in land resource is also an advantage in using Solar PV for Facades. As electrical output of Solar PV Facade can be consumed in the high-rise building itself, it is a form of distributed generation with captive consumption avoiding transmission infrastructure & losses.

Keywords – Solar PV, High-rise Buildings, Facade,Thin Film

1. INTRODUCTION

Urbanisation is an integral part of development in modern world. Due to paucity of land resources, the urban areas are witnessing a growth in high-rise buildings. These buildings are densely populated & are major consumers of energy. They are also a source of GHG emissions presently by use of power generated from fossil fuel based sources.[3,13] India is blessed with abundant sunshine & solar energy is getting the importance it deserves in recent times. Distributed generation is a key aspect of Solar PV in India. Green building norms under TERI – GRIHA and IGBC-LEED certification processs require energy efficiency of about 14% for the Building Envelope & 10% of the total building energy be drawn from solar power.[7,29]Accordingly high-rise buildings in urban areas which are major consumers of energy need to be utilised as sites for Solar PV. Though roof-top Solar PV has been getting due attention, facades of high-rise buildings also offer a great opportunity for Solar PV. This research paper aims to assess the potential for monetary savings & reduction in GHG emissions using Solar PV Facades in high-rise buildings in Mumbai, India. The concept can also be applied to high-rise buildings in other parts of India. There is a need to include Solar PV Facades from the concept stage for high-rise buildings to ensure proper integration & minimum cost. Saving in land resource is also an advantage in using Solar PV for Facades. As electrical output of Solar PV Facade can be consumed in the high-rise building itself, it is a form of distributed generation with captive consumption avoiding transmission infrastructure & losses. This paper also examines the relative performance of mono-crystalline & thin film technologies used for Solar PV Facades & related payback periods.

2. OBJECTIVES

This research paper aims to assess the potential for using Solar PV Facades in high-rise buildings in Mumbai, India. This paper discusses the present status of different Solar PV technologies & facade types. It intends to examine the relative performance of mono-crystalline & thin film technologies used for Solar PV Facades in high-rise buildings of Mumbai in India using established software.. It also aims to analyse the monetary savings, related payback period & GHG emission reduction resulting from use of Solar PV Facades in high-rise buildings in Mumbai . It also attempts to discuss the advantages & challenges related to the concept.

3. METHODOLOGY & LITERATURE SURVEY

This research paper is organized according to the objectives stated above. The methodology adopted & literature survey (reference quoted in [ ]) comprises of the following initiatives:

Analysis of the present status of photovoltaics including different types of PV cells & their general properties.[17,18,21]

rends in the Solar PV development and global PV market.[17,18,21]

Present status of cell efficiencies for various technologies with particular reference to Thin Film technology.[11,12,14,17]

Analysis of integration of Solar PV into the building’s outer layers with reference to different kinds of facades.[3,8,13,19,26]

Compilation of data on high-rise buildings in Mumbai, India & their surface area suitable for Solar PV facades.[10]

Assessment of MWh output profile & greenhouse gas (GHGs) emission reduction using Solar PV facades in high-rise buildings in Mumbai, India with comparative figures for mono-crystalline & CdTe.[2,10]

Compilation of data on utility power tariff in Mumbai & corresponding payback period for Solar PV facades.[22,23,24,25]

Analysis of advantages & challenges related to Solar PV & thin film technology for building facades.

[11,12,14]

4. SOLAR PV TECHNOLOGY

Sun is an abundant source of energy & research has been undertaken since long on harnessing the same for generation of electricity. Solar Cells are used in converting sunlight into electricity through photovoltaic effect. An assembly of interconnected solar cells is called a solar module.[18,19]

Photovoltaic has seen a Compound Annual Growth Rate (CAGR) of PV installations of 41 % between 2000 to 2015. The fabrication of solar cells has covered a large spectrum including Silicon based solar cells grown on Si wafers, thin films, dye sensitized solar cells and organic solar cells .[11,12,14,17]

Polycrystalline cells are produced by casting hot, liquid silicon into square molds further cooled to form solid blocks, which are sliced like single-crystalline silicon. This is cut into rectangular rods which are sliced into thin wafers. These are used for manufacturing solar cells & modules. Polycrystalline cells are the most commonly used.

Mono-crystalline cells are created in a process in which the ingots are manufactured according to the Czochralski process. The ingots have the same crystal orientation through their whole length. & have a circular cross section.

Thin-film technology cells are manufactured by a process of printing on glass in many thin layers. Thin film cells put thin layers of photovoltaic materials on top of a substrate having a light spectrum within which they convert sunlight to usable energy. The common types of thin film technologies are amorphous silicon, cadmium telluride, and copper indium gallium selenide. Cadmium Telluride has gained popularity in recent times.

Figure 1 & 2 below give a comparison of various Solar PV cell types in terms of efficiency. [17]

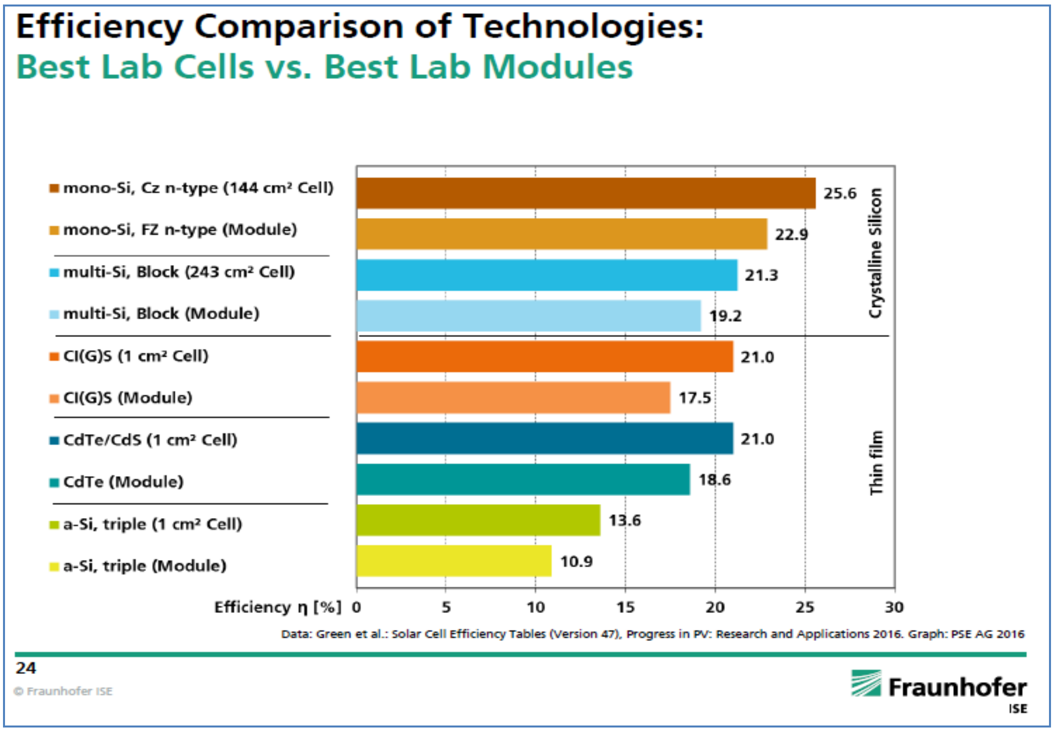


Figure 1

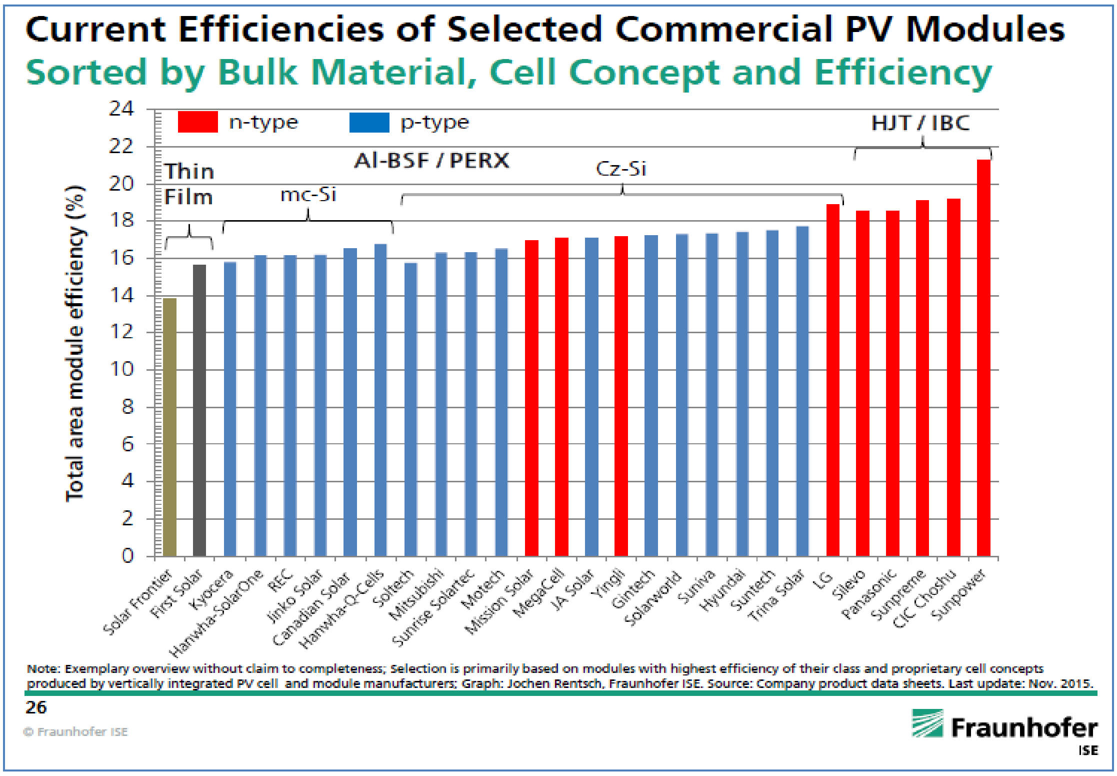


Figure 2

The relative market share of various Solar PV technologies in the world market is as given in Figure 3 below. It can be seen that multicrystalline cell enjoy a major share of the market.[17]

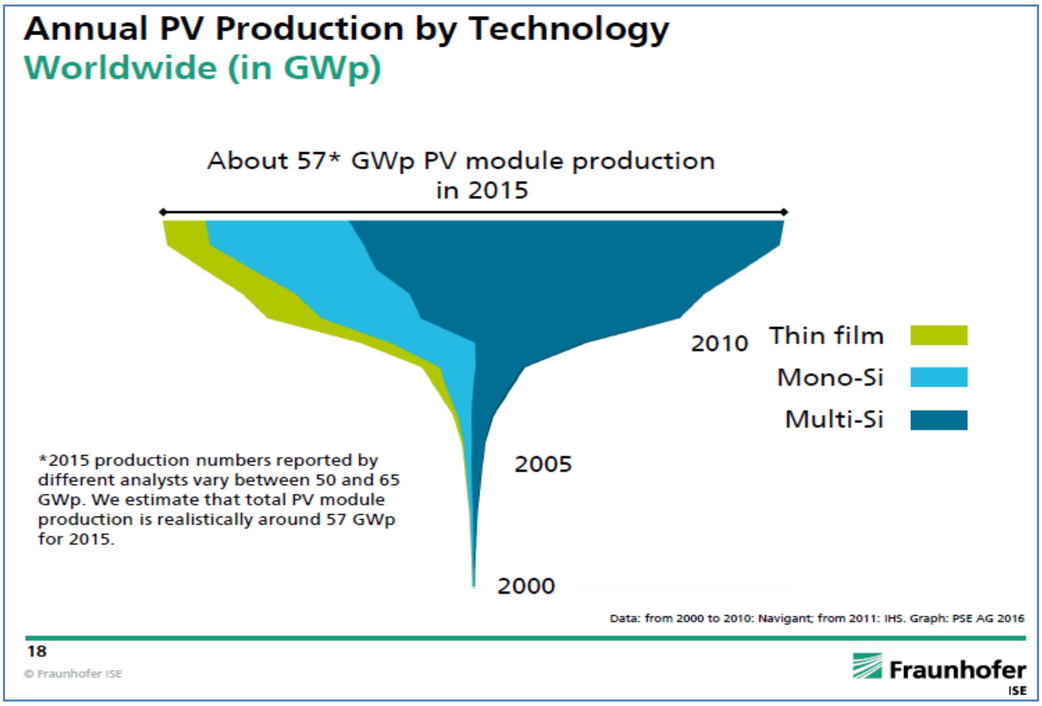


Figure 3 – PV Market Share by Cell Technology

5. THIN FILM SOLAR PV

Thin-film technology cells are manufactured by a process of printing on glass in many thin layers. Thin film cells have thin layers of photovoltaic materials & substrate having a light spectrum within which they convert sunlight to usable energy. Since thin film cells are much thinner (nm to few µm) as compared to crystalline cells (200 µm) , they are flexible , lighter with less friction. Thin-film PV modules offer the advantage of flexible, curved shapes and a lighter weight compared to the crystalline modules. Thin-film PV modules can also attain efficiencies similar to the crystalline modules, as shown by recent research. .[11,12,13,14] The price per watt-peak has also become comparable to crystalline modules. The above features make thin-film PV a technology optimum for Solar PV Facades

The common types of thin film technologies are cadmium telluride (CdTe), copper indium gallium selenide (CIGS) , amorphous silicon & Gallium Arsenide[11,12,13,14] which are detailed as follows-

Cadmium telluride (CdTe) is a dominant thin film technology with a majority of thin film market share. The cell's lab efficiency has improved in recent years & may be comparable to crystalline in near future.

Copper indium gallium selenide - A CIGS cell uses an absorber made of copper, indium, gallium, selenide . The fabrication is by vacuum processes including co-evaporation and sputtering. Non-vacuum process has also been developed recently.

Amorphous silicon – It is is a non-crystalline, allotropic form of silicon and well-developed thin film technology. It is an alternative to crystalline silicon. Silicon-based devices avoid drawbacks of CdTe and CIS modules such as toxicity and humidity issues. The silicon-based module types common are - amorphous silicon cells, amorphous / microcrystalline tandem cells & thin-film polycrystalline silicon on glass.

Gallium arsenide thin film cells- It is also used for single-crystalline thin film solar cells. Although expensive, GaAs, has record highest-efficiency for single-junction solar cell at 28.8%.They are used in solar panels on spacecrafts . They are also used in concentrator photovoltaics, using lenses to focus sunlight on a small GaAs concentrator solar cell.

Emerging photovoltaics - Other emerging thin-film technologies under development are termed as third generation photovoltaic cells and include quantum dot, copper zinc tin sulfide, nanocrystal, micromorph, perovskite ,organic, dye-sensitized, polymer solar cells

Transparent solar panels use a tin oxide coating along with titanium oxide that is coated with a photoelectric dye. The solar cells use ultraviolet radiation as well as infrared. The applications include windows used for power generation, lighting and temperature control.

Figure 4 below indicates the global growth in production of various thin film modules.[17]

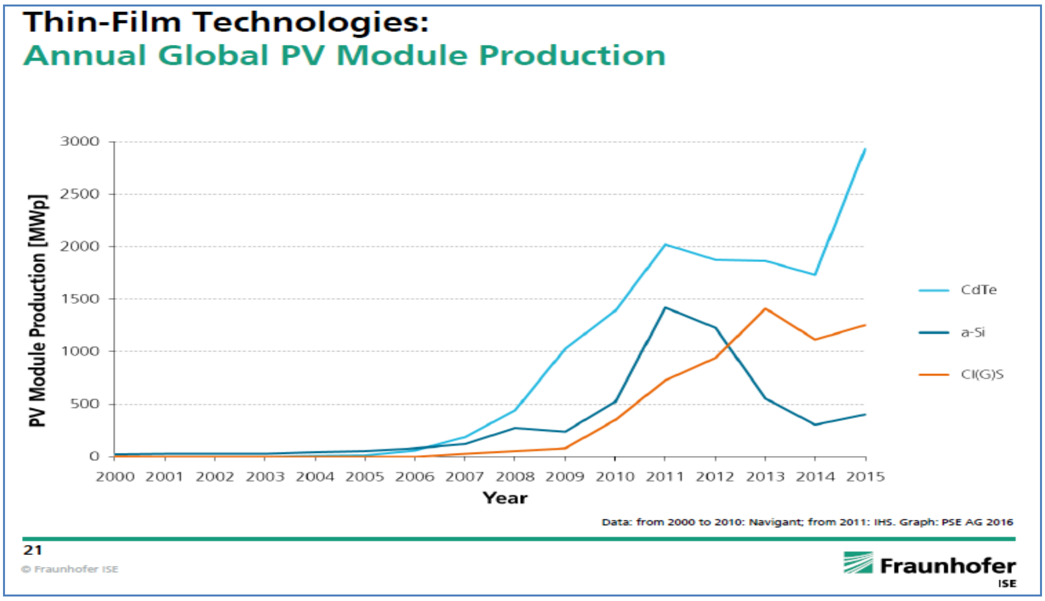


Figure 4

6. SOLAR PV FACADES

Facade is the public face of a building and defines the look of a building. The facade acts as a barrier between the interior and the exterior environment. The facade can shield from solar insolation reducing heating/cooling loads and improving distribution of daylight. [1, 3]

There are two main building facade systems suitable for Solar PV - Rainscreen Cladding (Ventilated Facade) and Curtain Walling.[4,5,6]

Solar PV Facades - Rainscreen Cladding (Ventilated Facade)

Rainscreen cladding is used in new as well as renovated buildings. It consists of a stainless steel sub-frame fitted with cladding panels. The stainless steel cladding rails and fixing brackets are bolted onto the internal wall. The cladding panels form a ventilated cavity with the internal insulated

wall .The cavity also acts as barrier for driving rain protecting the insulated inner wall. Opaque or transparent solar panels can be used as needed. The ventilated cavity facilitates better cooling for the solar panels.

Solar PV Facades - Curtain Walling Systems

Curtain walls are supported by the building floors & columns .They are airtight and resist wind and weather. Curtain walls use aluminium or stainless steel frame & are lightweight, fitted with transparent or opaque solar panels.

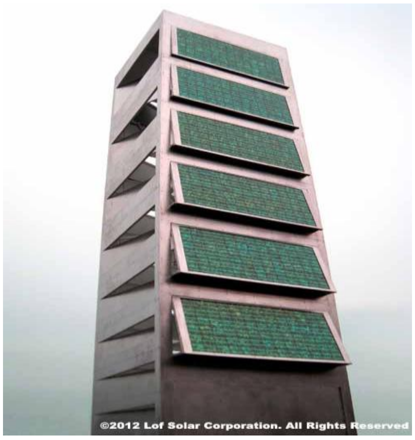
Solar PV Façade is aesthetically pleasing, generates electricity & helps in better energy performance of the building. Transparency in Solar PV Façade can be obtained by spacing between solar cells or see through thin film solar cells. Light effects can also create nice patterns on the same.[1,7,9]

For best power generation south facing walls (also southeast & southwest) are ideal in the northern hemisphere. Shadows need to be avoided. The cabling system is designed to integrate with the installation & remain hidden from sight. The electricity generated by Solar PV Façade is fed to an inverter which converts DC supply to AC & connects to the consumer.[15]

An example of Solar PV Façade is the City Hall in Freiburg (Germany)[16]. With a surface of approximately 13.000 m², the overall PV output of 220 kWp is generated by a total of 880 solar modules, using special seamless double-glass modules with the dimensions of 3.5 m height on 60 cm width, weighing 100 kg each. The City Hall completely matches with the principal standards of a zero-energy building. [3,13]

Further , it is also possible to use transparent Solar PV facade which not only absorbs energy for photovoltaic,but also transmits energy to ensure heat & light gain for the building .[26]

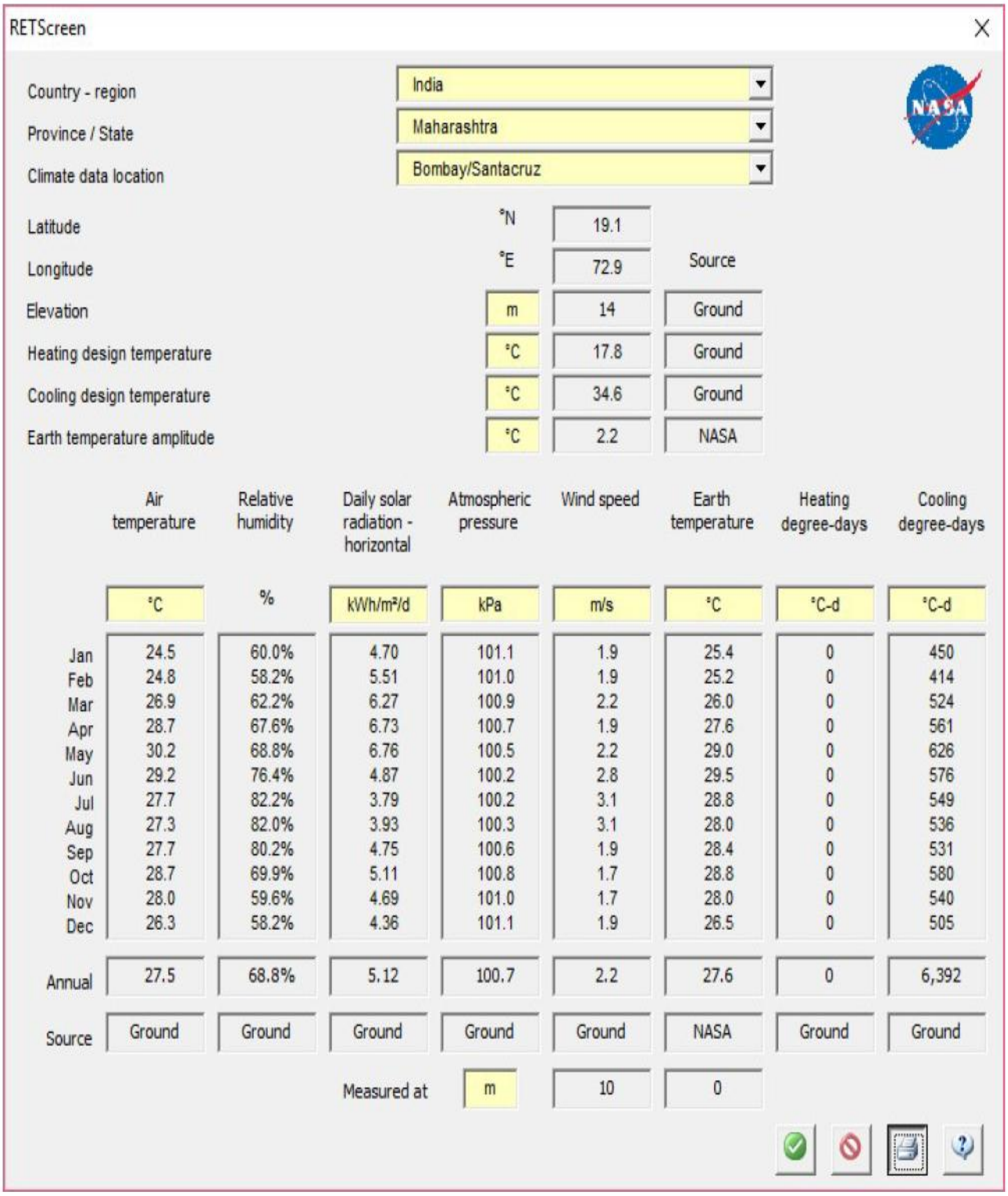
Use of tracking may also be developed for Solar PV Facade to increase output.[1]



City Hall in Freiburg (Germany)[16] **Solar PV Façade with tilt[30]**

7. ASSESSMENT OF POWER PROFILE IN BUILDINGS USING SOLAR PV FACADES IN MUMBAI , INdia

RETScreen 4 by Natural Resources Canada [2] is a software used to assess the performance of Solar PV power plant (or other renewable resources) for a particular location. RETScreen 4 has been used in this paper to assess the comparative output of mono-crystalline & CdTe technologies as applied to facades of high-rise buildings in Mumbai, as per Table 1 below. The ambient conditions taken for Mumbai are as per Figure 5 below .



RETScreen

Country - region	India		
Province / State	Maharashtra		
Climate data location	Bombay/Santacruz		
Latitude	°N	19.1	
Longitude	°E	72.9	Source
Elevation	m	14	Ground
Heating design temperature	°C	17.8	Ground
Cooling design temperature	°C	34.6	Ground
Earth temperature amplitude	°C	2.2	NASA

	Air temperature	Relative humidity	Daily solar radiation - horizontal	Atmospheric pressure	Wind speed	Earth temperature	Heating degree-days	Cooling degree-days
	°C	%	kWh/m²/d	kPa	m/s	°C	°C-d	°C-d
Jan	24.5	60.0%	4.70	101.1	1.9	25.4	0	450
Feb	24.8	58.2%	5.51	101.0	1.9	25.2	0	414
Mar	26.9	62.2%	6.27	100.9	2.2	26.0	0	524
Apr	28.7	67.6%	6.73	100.7	1.9	27.6	0	561
May	30.2	68.8%	6.76	100.5	2.2	29.0	0	626
Jun	29.2	76.4%	4.87	100.2	2.8	29.5	0	576
Jul	27.7	82.2%	3.79	100.2	3.1	28.8	0	549
Aug	27.3	82.0%	3.93	100.3	3.1	28.0	0	536
Sep	27.7	80.2%	4.75	100.6	1.9	28.4	0	531
Oct	28.7	69.9%	5.11	100.8	1.7	28.8	0	580
Nov	28.0	59.6%	4.69	101.0	1.7	28.0	0	540
Dec	26.3	58.2%	4.36	101.1	1.9	26.5	0	505
Annual	27.5	68.8%	5.12	100.7	2.2	27.6	0	6,392
Source	Ground	Ground	Ground	Ground	Ground	NASA	Ground	Ground
			Measured at	m	10	0		

Figure 5 – Mumbai Ambient – RETScreen4 Snapshot[2]

Table 1 – *RETScreen 4 for Solar PV Facade Output for Mumbai, India[2]*

Photovoltaic					
Type		mono-Si		CdTe	
Power capacity	kW	1,000.00		1,000.00	
Manufacturer		Canadian Solar		First Solar	
Model		mono-Si - CS6X-300M - MaxPowe		CdTe - FS-390W	
Efficiency	%	15.6%		12.5%	
Nominal operating cell temp.	°C	45		46	
Temperature coefficient	% / °C	0.40%		0.24%	
Solar collector area	m²	6,398		8,000	
Control method		MPPT		MPPT	
Miscellaneous losses	%	7.0%		7.0%	
Inverter					
Efficiency	%	96.0%		96.0%	
Capacity	kW	1000.0		1000.0	
Miscellaneous losses	%	0.0%		0.0%	
Resource assessment					
Solar tracking mode		Fixed	Fixed	Fixed	Fixed
Slope	°	65.0	90.0	65.0	90.0
Azimuth	°	0.0	0.0	0.0	0.0

Month	**Daily solar radiation - horizontal**	**Daily solar radiation - tilted**	**Electricity exported to grid**	**Electricity exported to grid**	**Electricity exported to grid**	**Electricity exported to grid**
	kWh/m²/d	**kWh/m²/d**	**MWh**	**MWh**	**MWh**	**MWh**
January	4.70	5.61	142.43	115.31	147.23	118.19
February	5.51	5.76	132.34	101.27	136.70	103.51
March	6.27	5.21	132.45	89.13	136.85	90.91
April	6.73	4.27	105.82	58.81	109.07	59.69
May	6.76	3.47	89.41	47.46	91.89	47.96
June	4.87	2.62	66.18	43.42	67.74	43.88
July	3.79	2.29	60.56	41.08	61.64	41.35
August	3.93	2.58	67.90	43.73	69.19	44.07
September	4.75	3.58	89.47	59.09	91.88	60.02
October	5.11	4.87	122.86	91.00	127.36	93.34
November	4.69	5.49	133.32	107.57	138.52	110.78
December	4.36	5.40	136.00	111.81	141.00	115.00
Annual	**5.12**	**4.25**	**1,278.74**	**909.67**	**1,319.07**	**928.72**

The area occupied by solar panels depends on the type of panels used. Thin Film panels need more area per MW compared to crystalline panels. The annual output depends on the building's geographical location, the orientation of the solar panels, the tilt of the solar panels, the technology used and shadows in the PV area. For a low angle of incidence, the output of Solar PV Façade may be higher than roof-top Solar PV.

The monthly output variation profiles for both 65^0 tilt & vertical orientation (figure 6 & figure 7 below) for Solar PV Facades in Mumbai, India indicate that CdTe gives overall higher annual output per MW installed as compared to monocrystalline .

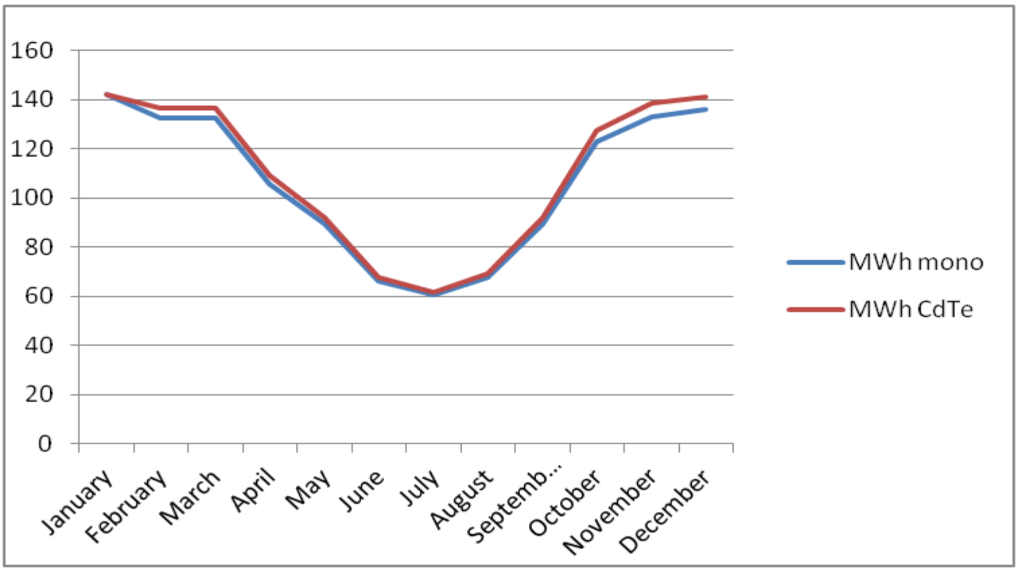


Figure 6 - Monthly output variation for Solar PV Facade for Monocrystalline & CdTe with 65^0 tilt in Mumbai, India[2]

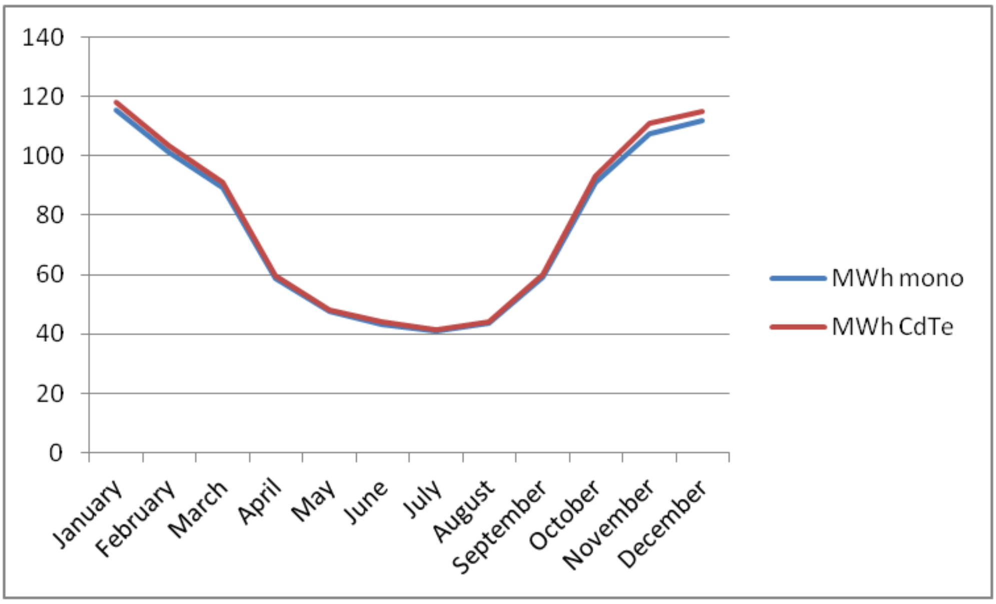


Figure 7 - Monthly output variation for Solar PV Facade for Monocrystalline & CdTe with 90^0 tilt (vertical) in Mumbai, India[2]

The results for various buildings are summarised in Table 2 below. The average present cost of utility power (BEST/Reliance/Tata-HT-III-Residential) – is taken as INR 8.92 per KWh to calculate the savings[22,23,24,25]. RETScreen 4 has been used as indicated above for arriving at the results. The surface area for Solar PV Facades taken are approximate & based on layouts published by the respective developers of the buildings[10] & same need to be estimated in detail on a case to case basis.

Table 2 – Solar PV Facade Capacity Proposed & Generation for High-rise buildings in Mumbai, India[2,10,22,23,24,25]

High-rise Building Name	Building Ht. Mtr.	Solar PV Facade Surface Area Sq. Mtr.	Solar PV Capacity Proposed KWp	Annual Generation MWh with vertical CdTe modules	Annual Generation MWh with tilt 65^0 CdTe modules	Annual Savings Million INR with tilt 65^0 CdTe modules	Net annual GHG emission reduction tCO2
World One	442	53040	6630	6152.64	8745.434	78.00927	8735.025
Omkar 1973	320	64000	8000	7424	10552.56	94.12883	10540
Minerva	307	30700	3837.5	3561.2	5061.931	45.15242	5055.906
Sky Suites	291	29100	3637.5	3375.6	4798.117	42.7992	4792.406
Sky Forest	281	28100	3512.5	3259.6	4633.233	41.32844	4627.719
KUL Couture	275	13750	1718.75	1595	2267.152	20.22299	2264.453
Orchid Hts.	274	32880	4110	3814.08	5421.378	48.35869	5414.925
The Park	268	134000	16750	15544	22094.42	197.0822	22068.13
One Avighna	266	26600	3325	3085.6	4385.908	39.1223	4380.688
Nathani Hts.	262	26200	3275	3039.2	4319.954	38.53399	4314.813
The Imperial	256	30720	3840	3563.52	5065.229	45.18184	5059.2
Ahuja Twrs.	248	24800	3100	2876.8	4089.117	36.47492	4084.25

The results for Solar PV Facades for various high-rise buildings in Mumbai (Table 2 above) indicate an opportunity for substantial savings in electricity costs as well as reduction in GHG emission.

8. PAYBACK PERIOD

The payback period depends on several factors, the most significant of which are the cost of the technology used in connection with system integration, sun conditions and the local cost of energy. Integration into a building reduces the price of solar power generated by the system because the solar panel façade serves both as a façade and as an electricity supply.

The sample calculation for the payback period for 1000 KWp Solar PV Facade capacity for Mumbai, India may be based on the following assumptions –

Average present cost of utility power (BEST/Reliance/Tata-HT-III-Residential) – INR 8.92 per KWh

[22,23,24,25]

Average present cost of Glass Facade – INR 6,000 per sq. Meter [27]

Average present cost of Solar PV for Facade – INR 80,000 per KW[28]

The payback period can be calculated as follows -

Facade Area needed per KWp is 8 sq. meter [2]

Hence for 1000 KWp , 8000 sq. meter area is considered

It is assumed that all generation by Solar PV will be consumed by the building connected with grid under net metering.

Since generation per year with 65^0 tilt 1000 KWp CdTe modules is 1319.07 MWh ,

the saving per year is 1319070 X INR 8.92 = INR 11,766,104 **(A)**

The initial investment for 1000 KWp is -

(Solar PV Cost) less (Cost of Glass Facade) = (80000 X 1000) – (8000 X 6000) = INR 22,000,000 **(B)**

Comparing figures B & A above, it is apparent that the payback period is less than 2 yrs.

9. CASE STUDIES

The following case studies can be considered small scale examples of the concept of Solar PV Facade discussed

above -

1. **Installation for Festo by Tata Power Solar at Noida,Near Dehi,India**[32]

This system installed in 2011 is rated 19.52 KW , uses 80 Wp Tata Power Solar modules , generates 17,106 KWh per year & helps in avoiding 13.2 tonnes of CO_2 per year.

FESTO is a German company dealing in factory and process automation technology for over 300,000 customers, in more than 200 industries worldwide.As part of their plans to invest in clean energy in their Indian facilities,FESTO intended to power the office premises with renewable energy and reduce the usage of energy for cooling the building during summers. Tata Power Solar proposed a Solar PV Facade system, which would generate the required solar energy to power their office & also keep it cool during summers by blocking direct sunlight. Stainless steel structures fitted on south facing façade of the building to mount the panels at the time of building construction working with design consultants ensured the aesthetics. To maximise energy generation, a tilt was incorporated in the structures. Reduction of heat helped in reducing the energy required for cooling. Normal load,computer and lighting load were powered by solar power . Two days battery back up power was used avoiding a separate UPS for computer and other applications.

2. **Polysolar Solar PV Facade for Future Business Centre - Cambridge 2013**[33]

This system rated 4.6 KW & supplied by Polysolar for Future Business Centre(FBC) in Cambridge aims to generate renewable energy utilising an artistic façade to achieve BREEAM Excellent requirement .It uses panels PS-A (100 watts) opaque,PS-C901 Transparent (90 Watts) doubleglazed (DGU). The Future Business Centre(FBC) in Cambridge is a purpose built incubation centre for social and environmental enterprises, the first of its kind. Polysolar provided the PV glazing for the stairwell curtain wall and the decorative rainsceen cladding. It was the first truly transparent curtain wall of this type employed within the UK. The installation uses Polysolar argon filled double-glazed PS-C series transparent units mounted in Reynaers curtain wall system. The PS-A-Series opaque units and the N-velope mounting frame provide an efficient bonded rainscreen façade combineing the benefits of a highly thermal efficient building cladding material with renewable energy technology. Polysolar's thin-film solar photovoltaic glass,when fitted as a double glazed unit,offer U-values of 1.2 W/m2K and G-values of 0.42. These figures are fundamental in driving the building into the highly coveted BREEAM category .

10. ADVANTAGES

The advantages of Solar PV Facades & Thin Film technology in India can be listed as follows –

1. It saves the utilisation of precious land resource of minimum 4 acres per MWp needed for ground mounted Solar PV.[18,20]
2. It has lower environmental impact as excavation work involved in ground mounted plants is avoided.[6,20]
3. With ongoing research , the efficiency of thin film modules is likely to improve [17].Use of tracking in Solar PV Facade may also be developed.[1]
4. Thin film CdTe modules have a higher annual output compared to crystalline modules in India due to their better temperature coefficient & better low-light operation. Crystalline panels respond to wavelengths from 400-1000nm, compared to thin film cells which do so from 250-1750nm , giving thin film advantage in low-light conditions.[2,11,12,14,17]
5. As electrical output of Solar PV Facade can be consumed in the high-rise building itself, it is a form of distributed generation with captive consumption avoiding transmission infrastructure & losses.[4,19] Electricity production

6. It offers insulation & may lead to energy savings in building heating & cooling.[7,29]
7. It helps in reducing noise inside building due to acoustic isolation.[7,29]
8. It is a protective cover for the building structure from weather elements.[7,29]
9. It improves the aesthetics of the building.[7,29]

11. Challenges

The challenges for Solar PV Facades in India can be listed as follows –

1. As Solar PV Façade may hinder ventilation , heating up of the interiors may happen.[7,29]
2. There is absence of integrated codes, standard and regulations in regard to Solar PV Facade systems.[7,29]
3. The customer and all the construction value chain members have to be convinced on the importance of Solar PV Facades for the particular project from the project inception stage till the construction is over. [7,8,29]
4. Trained personnel are needed for execution of Solar PV Façade.[7, 29]
5. Cleaning of Solar PV Façade has to be regular as dirt may reduce the output.[7, 29]
6. The systems for mounting of solar panels in a facade need to be further developed to facilitate best angle of inclination without compromising the functions as a facade.[7, 29]

12. CONCLUSION

This research paper establishes that there is potential for substantial monetary savings & reduction in GHG emissions if Solar PV Facades are used in high-rise buildings in Mumbai,India. The concept can also be applied for high-rise buildings in other parts of India as well. The payback period of less than 2 years is also very attractive. There is a need to include Solar PV Facades from the concept stage for high-rise buildings to ensure proper integration & minimum cost. Thin Film technology is a good choice for Solar PV Facades in India as demonstrated from the results with CdTe modules in this paper. Saving in land resource is also an advantage in using Solar PV for Facades. As electrical output of Solar PV Facade can be consumed in the high-rise building itself, it is a form of distributed generation with captive consumption avoiding transmission infrastructure & losses.

As Green building norms under TERI – GRIHA and IGBC-LEED certification processs require energy efficiency of about 14% for the Building Envelope & 10% of the total building energy to be drawn from solar power, Solar PV facades help the high-rise buildings in meeting there norms .[7,29]

Further research in India is needed to arrive at standards for integration of Solar PV Facades with high-rise buildings to ensure all the benefits of Facade & Solar PV are utilised. The systems for mounting of solar panels in a facade need to be further developed to facilitate best angle of inclination without compromising the functions as a facade. Recent developments include Luminescent Solar Concentrators (LSC) which use colloidal quantum dots & total internal reflection to collect sunlight more efficiently as per Los Alamos National Laboratory ,USA[31]. This is ideal for Solar PV Facades & may help in ensuring energy neutral buildings in the future in line with the global trend.

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