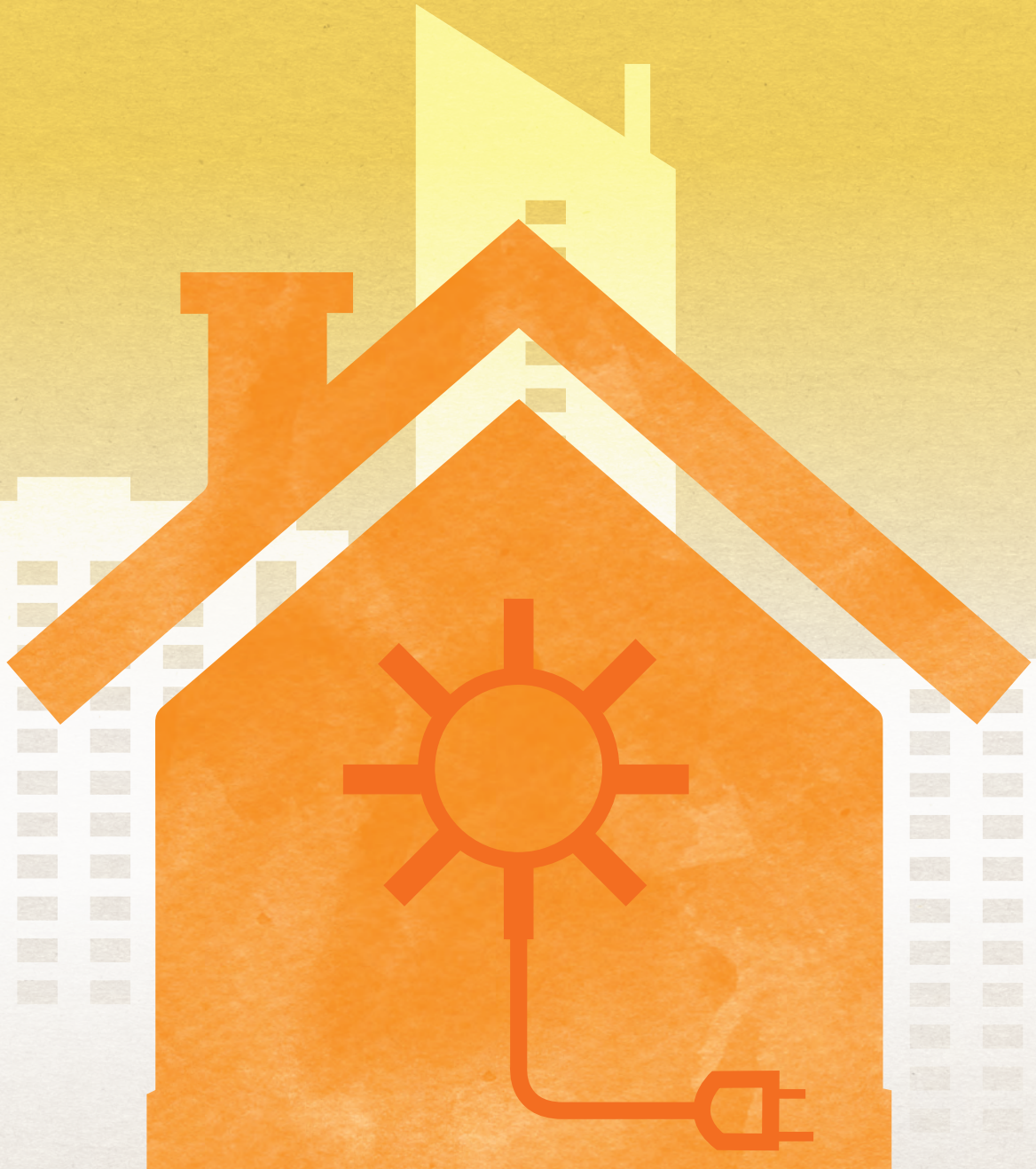


Renewable Energy Onsite Generation and use in Buildings



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June 2017

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Prayas (Initiatives in Health, Energy, Learning and Parenthood) is a non Governmental, non-profit organization based in Pune, India. Members of Prayas are professionals working to protect and promote the public interest in general, and interests of the disadvantaged sections of the society, in particular. Prayas (Energy Group) works on theoretical, conceptual regulatory and policy issues in the energy and electricity sectors. Our activities cover research and intervention in policy and regulatory areas, as well as training, awareness, and support to civil society groups. Prayas (Energy Group) has contributed in the energy sector policy development as part of several official committees constituted by Ministries and Planning Commission. Prayas is registered as SIRO (Scientific and Industrial Research Organization) with Department of Scientific and Industrial Research, Ministry of Science and Technology, Government of India.

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Greentech Knowledge Solutions Pvt. Ltd. (GKSPL) is a Clean Energy Research and Advisory firm which offers services across Renewable Energy, Energy Efficiency, and Green Buildings domains. GKSPL has been involved in providing technical support for design of several energy-efficient buildings, studies related with integration of renewable energy in buildings, conducting technical training programmes for building design professionals and undertaking policy studies in the field of energy-efficient/low carbon buildings.

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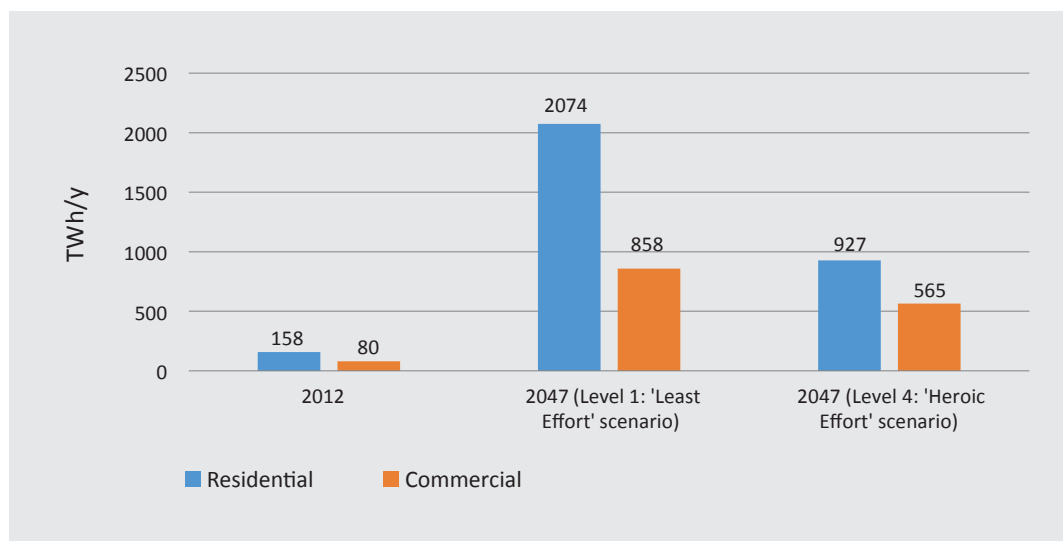
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1 : Introduction and Literature Review

1.1 Background

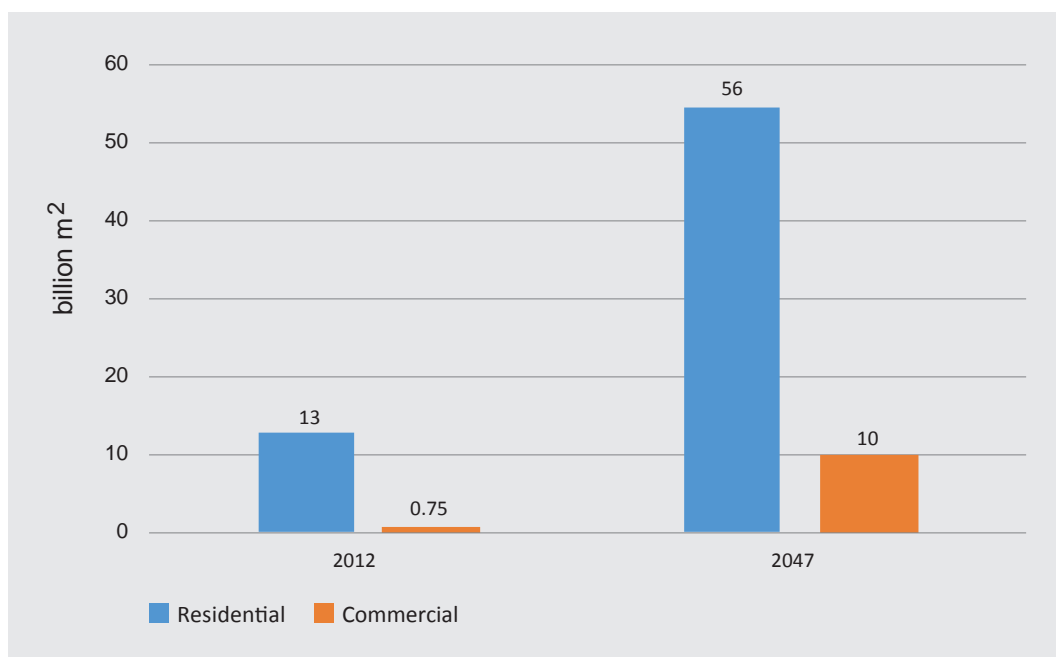
Across the world, buildings use about 40% of total global energy, and in the process, account for approximately 1/3rd of GHG emissions.¹ Of the total electricity consumption in year 2014–15 in India, residential and commercial buildings accounted for ~23% and ~8% respectively.² Projections by NITI Aayog³ under different scenarios (Figure 1) show that the electricity consumption for the residential sector is expected to increase 6–13 times, and 7–11 times for the commercial sector, from 2012 to 2047. This increase in electricity consumption in buildings is primarily attributed to the increase in building stock, with the residential sector built-up area expected to increase by ~4 times, the commercial sector by ~13 times from 2012 to 2047⁴ (Figure 2), expansion of electrification in rural areas as well as an increased intensity of electricity consumption in urban buildings, mainly due to the rapid growth of air conditioning.

Figure 1 : Projection of energy consumption under best (Level 4) and worst (Level 1) scenarios



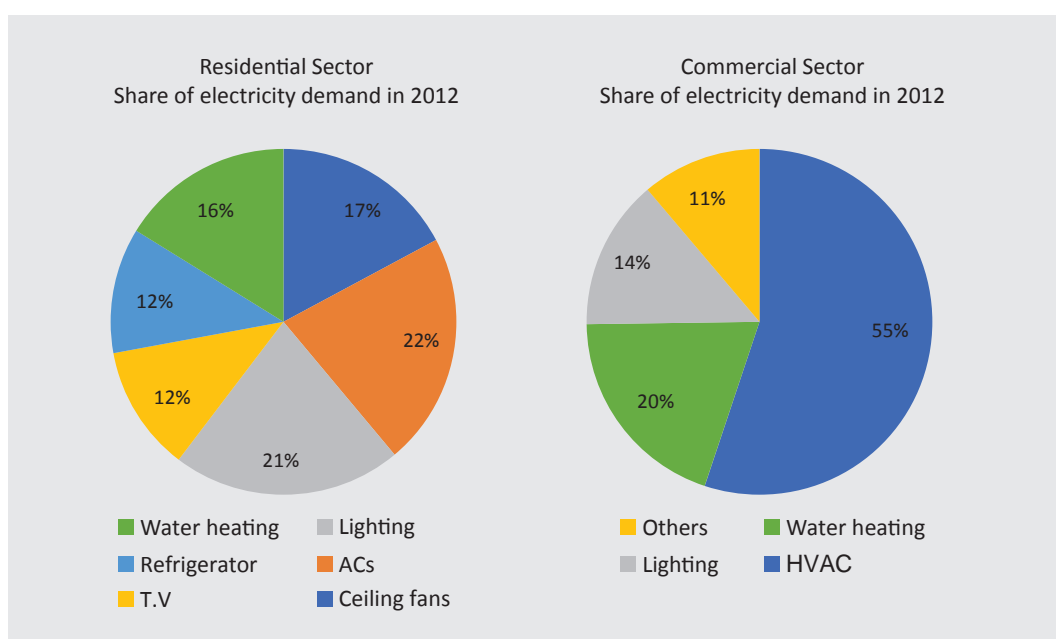
1. <http://www.unep.org/sbci/AboutSBCI/Background.asp>
2. Energy Statistics 2015; Ministry of Statistics and Programme Implementation, Govt. of India
3. India Energy Security Scenario (IESS) 2047, NITI Aayog
4. Ibid

Figure 2 : Projection of built-up area



The share of energy demand (excluding cooking energy) in residential and commercial building sectors in 2012⁵ is presented in Figure 3. Space cooling and ventilation (Ceiling fans + ACs) account for the largest demand of 37% in the residential sector and 55% (Heating, Ventilation and Air Conditioning (HVAC)) in the commercial sector. Water heating and lighting are the other major end-uses of energy in both residential and commercial buildings.

Figure 3 : End-use wise energy demand (excluding cooking energy) in residential and commercial building sectors (2012)



5. Ibid

In the light of the above discussion and in order to minimise energy consumption in buildings, it is important that the new building stock should be designed for thermal comfort and energy efficiency. This can be achieved through incorporation of passive design measures⁶ and the use of efficient systems and appliances⁷.

To further reduce energy demand, a proven solution is to integrate renewable energy systems which can generate energy onsite and allow for its consumption within the building. This not only helps in reducing the dependence of the buildings on the electricity grid, but also helps in reducing GHG emissions by replacing primarily fossil fuel based grid electricity with renewable energy. It also helps to reduce the transmission and distribution (T&D) losses of the electricity grid, which are very high (~23% in 2014–15⁸) in India.

Direct onsite renewable energy use in buildings has significant potential and forms one of the key blocks within the larger move by India towards greater use of renewable energy. The Government of India has set a target of 175 GW of renewable energy capacity by the year 2022, which includes 100 GW from solar, out of which 40 GW is to be generated from roof top solar or onsite solar energy generation in buildings. Similarly, target for a solar thermal collector (mainly to be installed on buildings) installed area is set at 20 million m² by 2022.

In addition to the policy intent to utilise buildings for renewable energy generation, the building codes such as the Energy Conservation Building Code (ECBC) and the National Building Code (NBC) as well as various green building rating systems (IGBC, LEED, GRIHA, EDGE) promotes use of Renewable Energy (RE) in buildings. Yet, the penetration of RE in buildings remains limited in India.

1.2 Objective and Scope of Study

The present study focuses on identifying the opportunities and challenges in realising the potential of onsite RE generation and use in buildings in India. It includes:

- Review of renewable energy technology options for use in buildings,
- Review of policies and regulations for renewable energy use in buildings,
- Case studies of building wherein considerable amount of renewable energy is used and
- Interaction with key stakeholders to understand key challenges, opportunities and action points in further increasing the effective use of RE in buildings.

Building sectors covered in this study include residential, commercial, and institutional buildings, but excludes industrial buildings with process heating/cooling and electricity generation applications; and focuses on RE technologies (used/ installed within the building premises), which include solar Photovoltaics (PV), solar water heaters, solar concentrators, air-source heat pumps and biogas generation.

6. Passive design features include facing longer facades towards north and south direction, shading for windows, wall and roof insulation, optimising window to wall ratio for maximising daylight utilisation and designing spaces for natural ventilation, etc. For details, please see <http://www.beepindia.org/>.

7. BEE star rated equipment and appliances, LED lighting, efficient chillers, heat recovery, free cooling, radiant cooling, etc. For details, please see <http://www.beepindia.org/>.

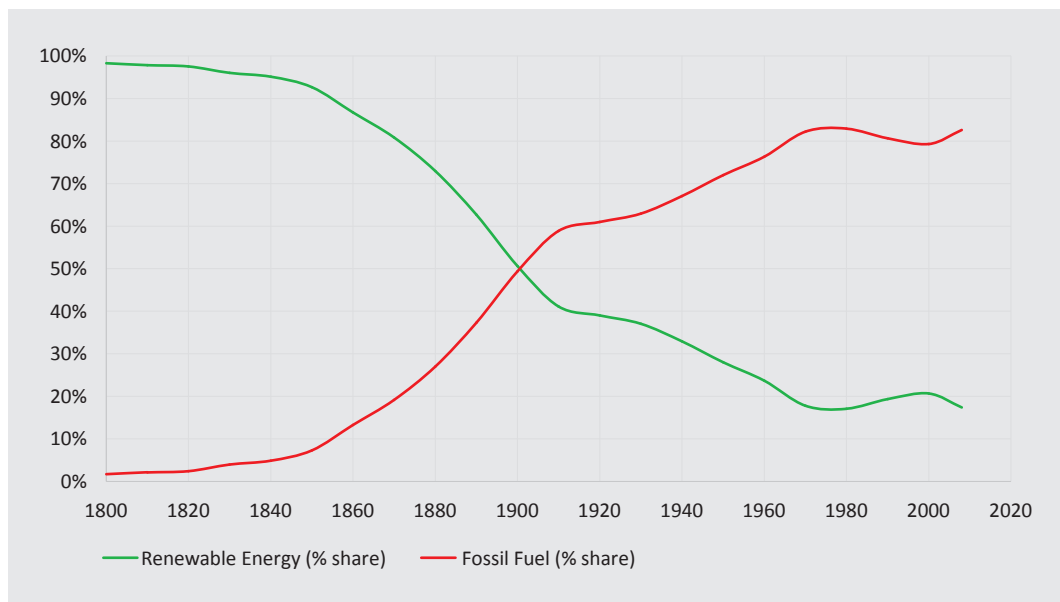
8. http://www.cea.nic.in/reports/monthly/executivesummary/2016/exe_summary-12.pdf

1.3 Literature Review

1.3.1 History of global renewable energy use and its outlook

Renewable energy (mainly biomass) was the main source of energy till the year 1800, after which the use of coal as primary source of energy increased drastically and the share of fossil fuel (mainly coal) increased to ~50% by 1900. After 1900, crude oil and natural gas production started increasing and contributed to ~56% of the total world primary energy consumption in the year 2000, while the share of renewable energy decreased to ~20%.⁹

Figure 4 : Share in total primary global energy consumption



While the share of renewable energy in the overall energy consumption has decreased, the overall energy consumption has increased rapidly in recent years. Total primary energy consumption across the world has increased from ~364 EJ in 1990 to ~580 EJ in 2012, and projections by the U.S. Energy Information Administration suggest that it will rise to ~860 EJ in 2040.¹⁰

Going forward, it is noted that most predictions have projected a significant increase in primary energy consumption across the globe. At the same time, these studies also project a reversal in the trend of renewable use where it is expected to rise instead of drop as has occurred in the past. The International Renewable Energy Agency (IRENA) has developed a renewable energy roadmap¹¹ (includes 40 countries, representing 80% of the world's total final energy consumption), with a target to double the renewable share in total primary energy supply (TPES) from ~18% at 2014 to ~36% in 2030, along with ten solutions to achieve it. The International Energy Agency (IEA), under the 450 Scenario (with a 50% chance of limiting global warming to 2°C)¹², suggests nearly 60% of the electricity generated in 2040 to come

9. <https://ourworldindata.org/energy-production-and-changing-energy-sources/>

10. [http://www.eia.gov/outlooks/ieo/pdf/0484\(2016\).pdf](http://www.eia.gov/outlooks/ieo/pdf/0484(2016).pdf)

11. www.irena.org/DocumentDownloads/.../IRENA_REmap_2016_edition_report.pdf

12. http://www.iea.org/publications/freepublications/publication/World_EnergyOutlook2016Executive_SummaryEnglish.pdf

from renewables, almost half of this from wind and solar PV. The World Energy Council projected¹³ the renewable energy share to be 23.4% to 40.7% in TPES by 2050 under two different scenarios.

1.3.2 International Indian scenario: RE potential, target and achievement

As per the Ministry of New and Renewable Energy (MNRE), the total potential of all RE technologies in India is ~1100 GW¹⁴, out of which solar (~750 GW) has the highest potential (~68%) followed by wind (100 meter hub height), small hydro and bioenergy, with potential of 27%, 2% and 2.2% respectively. The Government of India has set the target of renewable energy installed capacity of 175 GW by the year 2022, which includes 100 GW from solar (40 GW from Rooftop Solar and 60 GW through Large and Medium Scale Grid Connected Solar Power Projects), 60 GW from wind, 10 GW from bio-power and 5 GW from small hydro-power. Similarly, the target for the solar thermal collector installed area is set to 20 million m² by 2022¹⁵. As on December 2015, India has installed 1020 MW of roof top solar capacity¹⁶, while the SWH installation¹⁷ is 8.9 million m².

1.3.3 Energy consumption in buildings

Different types of buildings have large variation in terms of overall energy consumption, types of equipment/appliances used, seasonal variation in demand, end-use energy break-up and space availability for RE systems. These variations in energy demand can be captured through the Energy Performance Index (EPI) in kWh/sq. m./year in terms of purchased and generated electricity divided by built up area in sq. m.

A survey conducted in India for multi-story middle class residential buildings (~1150 households) shows an average Energy Performance Index (EPI)¹⁸ of ~ 46 kWh/m².y, while the energy consumption in the peak summer could be 2–2.3 times as compared to that in the winter¹⁹ (Figure 5). The survey also shows that ~50% of households have an EPI ranging from 20 to 50 kWh/m².y (Figure 6), and that there is also a trend in overall shift towards the higher EPI range.

Another study conducted for ~800 commercial building (offices, hotels, hospitals and malls) shows an EPI ranging from 100 to 350 kWh/m².y²⁰ (Figure 7). The energy requirement for cooling in all types of buildings remains the highest (30–60%), while the energy requirement for water heating is also significant (Please see Figure 3). Limited space availability, particularly in case of high-rise buildings, constrains the amount of energy that can be supplied by solar energy.

13. https://www.worldenergy.org/wp-content/uploads/2013/09/World-Energy-Scenarios_Composing-energy-futures-to-2050_Full-report.pdf

14. Annual report (2015–16), Ministry of New and Renewable Energy (MNRE)

15. Ibid

16. Bridge to India estimates as on September 30, 2016

17. http://mnre.gov.in/file-manager/annual-report/2015-2016/EN/Chapter%201/chapter_1.htm

18. Energy Performance Index (EPI) is measured in kWh/m².y and it is the ratio of total annual electricity consumption (excluding the energy generated from renewable energy) for the building to its total built-up area (excluding the basements used for services and/or parking).

19. Household energy survey under Indo-Swiss Building Energy Efficiency Project (2012-16)

20. ECO-III Study on "Energy use in commercial buildings – National benchmarking study" (2011)

Figure 5 : Comparison of Average Monthly Electricity Consumption

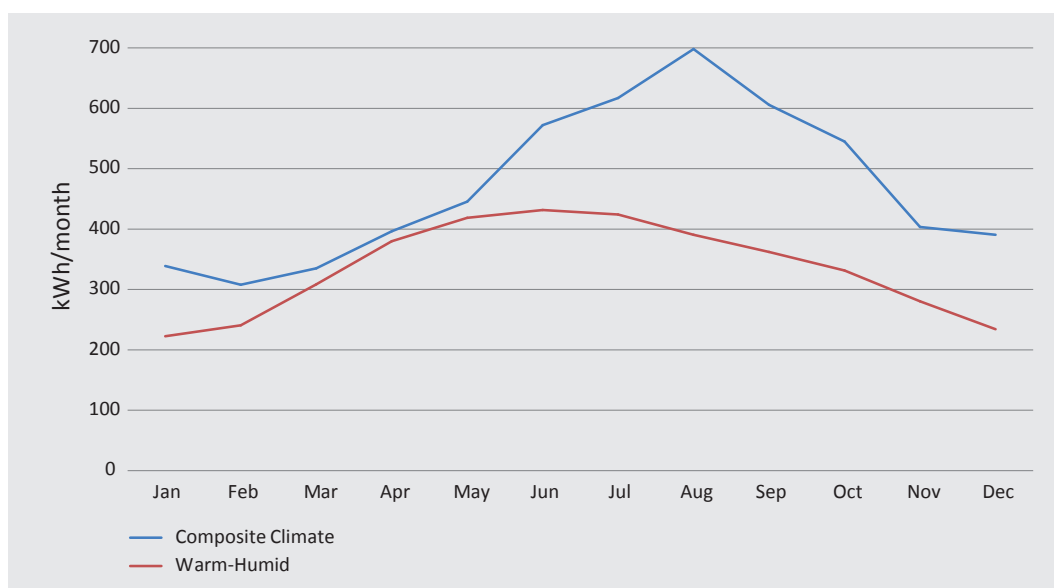


Figure 6: EPI distribution in high-rise residential buildings

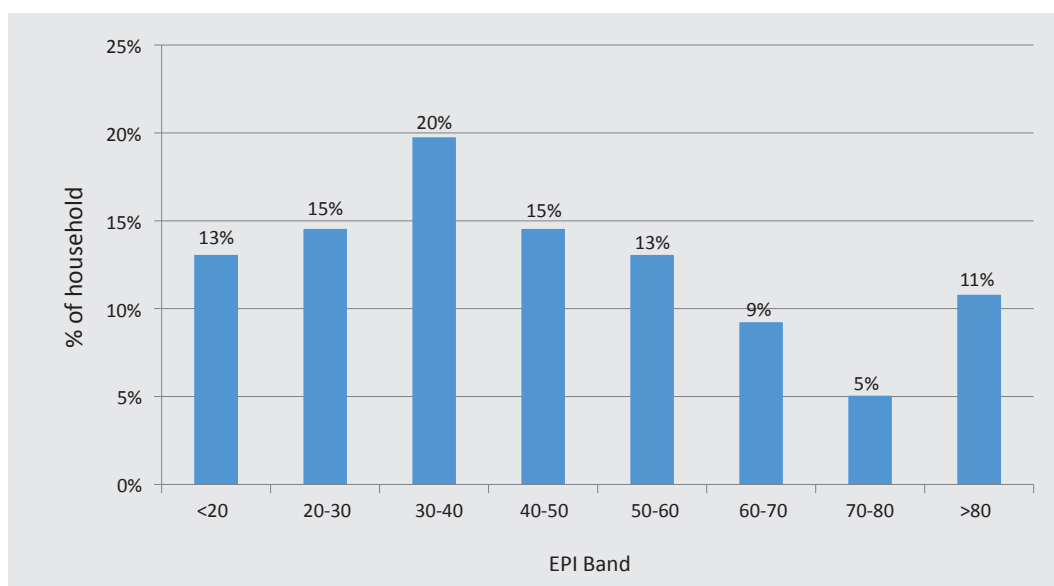
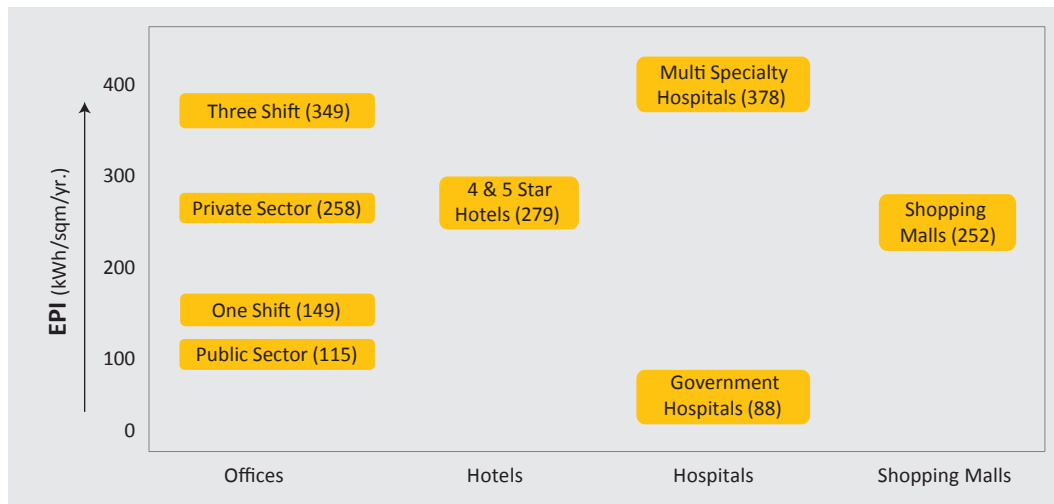


Figure 7: Large variation in EPI for different types of commercial buildings



1.3.4 Building codes and rating systems

In recent years a number of organisations have developed green building standards and rating systems. These are typically voluntary certifications for residential, commercial and industrial buildings. A building code is developed to align closely with standards, and rating systems provide for guidelines on energy conservation and green construction techniques. As an example, the National Building Code (NBC) of India, contains administrative regulations, development control rules and general building requirements; fire safety requirements; stipulations regarding materials, structural design and construction (including safety); and building and plumbing services. The NBC also serves as a Model Code for adoption by all agencies involved in building construction works, be it the Public Works Departments, other government construction departments, local bodies or private construction agencies. The Bureau of Indian Standards (BIS) is responsible for the development of NBC, and the first edition of the NBC was published in 1970. In the later years, NBC has been revised as new construction techniques and buildings material became available, and its scope expanded to address new challenges, such as environmental sustainability.

In India, Urban Local Bodies (ULBs) and development authorities have their own building bylaws which are mandatory for all construction within their jurisdiction. The local building bylaws are usually based on the National Building Code, which serves as model code providing guidelines for regulating building construction activity. In recent years, the NBC has integrated aspects of thermal comfort, energy efficient design and integration of renewable energy. In 2007, another code, called the Energy Conservation Building Code (ECBC) was developed by the Bureau of Energy Efficiency (BEE), and it is aimed at energy-efficient designs of commercial buildings. Apart from integration of solar water heating, the ECBC does not address the issue of renewable energy integration in buildings. Some states have made the ECBC mandatory, paving the path for its integration in local building bylaws. A revised ECBC with more provisions for Renewable Energy is also under development.

In addition to building bylaws and codes, several green building ratings systems have come into effect during the last 15 years. They promote green concepts and techniques in the building sector to address issues like water efficiency, energy efficiency, handling of waste and conserving natural resources. The green building rating systems available in India include the India Green Building Council (IGBC) part of the Confederation of Indian Industries (CII), Leadership in Energy and Environmental Design (LEED) for applications registered under Green Building Council of India (GBCI), Green Rating for Integrated Habitat Assessment (GRIHA) which was founded by The Energy Research Institute (TERI), and Excellence in Design for Greater Efficiencies (EDGE) which is promoted by the International Finance Corporation (IFC).

A comparison of provisions for RE systems in building codes and green building rating systems are presented in Table 1.

Table 1: Renewable energy and energy efficiency provisions in Indian building codes and rating systems

	Solar Thermal	Solar PV	Other RE
National Building Code of India by Bureau of Indian Standards (Proposed Draft of 2015)	Suggests use of RE on a voluntary basis; "All efforts should be made to utilise in the building, the renewable energy available in various forms"		
	<ul style="list-style-type: none"> - Solar water heating systems - Solar steam systems for cooking, laundry, etc. - Solar assisted refrigeration/air conditioning systems 	Solar Photovoltaic Systems	<ul style="list-style-type: none"> - Wind energy utilisation - Waste Utilisation (Waste heat and Solid waste) - Geothermal heating and cooling systems
Energy Conservation Building Code (ECBC) by Bureau of Energy Efficiency (Proposed Draft of 2016)	<ul style="list-style-type: none"> - Applicable to all commercial building having more than connected load of 100 kW or contract demand of 120 kVA - ECBC to limit itself to onsite RE generation only - Mandatory provisions of future installation of renewable energy in terms of dedicated area (Least of, area > 10 % of roof area or area required for the generation of energy equivalent to 1% of total peak demand or connected load) and necessary space for electrical systems 		
	Solar water heating <ul style="list-style-type: none"> - Only for facilities like hotels and hospitals with a centralised system - If building area < 20,000 m², at least 20% of the design capacity - If building area > 20,000 m², at least 40% of the design capacity - Electric (resistive type) heater as last resort 	Stringent requirement for Energy Efficient (EE) and Super Energy Efficient (SEE) category EE: 3% for special category (hotels/motels over 25,000 m ² , Resorts over 12,500 m ² , Universities over 30,000 m ² , IT parks and offices over 30,000 m ² and 2% for others SEE: 6% for special category and 4% for others	
Model Building Bylaw (2016) by Town and Country Planning Office	Mandatory for certain new buildings while system size is to be decided in consultation with the local bodies	Mandatory for residential and non-residential new buildings: Minimum 5% of connected load or 20 W/ft ² for "available roof space", whichever is less	--
Green Rating for Integrated Habitat Assessment (GRIHA v2015)	<ul style="list-style-type: none"> - Applicable to all buildings more than 2,500 m² (except for industrial complexes) - Mandatory on-site RE generation to offset a part of the annual energy consumption of internal artificial lighting and HVAC systems <ul style="list-style-type: none"> - Daytime Commercial/Institutional Buildings: 2.5% - Residential Buildings: NA - 24 X 7 occupied buildings: 0.5% - Points for additional on-site RE generation 		

IGBC Green Homes Rating System (v2.0)	Applicable for new and major renovated residential buildings including hostels, service apartments, resorts, motels and guest houses	
	Not mandatory; credit points for SWH system - Minimum demand: 20 L/ (person.day) - Hot water through SWH system as a percentage of total hot water requirement of the building	- Not mandatory; credit points for RE system - Renewable energy as a percentage of total connected load of the building
	- Different percentages for Individual Residential Unit and Multi-dwelling Residential Units	
IGBC Green New Buildings Rating System (v3.0)	- Applicable for air-conditioned/non air-conditioned buildings including offices, IT parks, banks, shopping malls, hotels, hospitals, airports, stadiums, convention centres, educational institutions (colleges, universities), libraries, museums, etc. - Divided in owner-occupied and tenant-occupied buildings	
	--	- Not mandatory; credit points for RE system - On-site Renewable Energy: Renewable energy as a percentage of total annual energy consumption of the building - Off-site Renewable Energy: Percentage of off-site Renewable Energy generated to the total annual energy consumption of the building - Different percentages for owner-occupied and tenant-occupied buildings

Some of the key observations that are very relevant for the present study derived from the review of building codes and green building rating systems suggest that:

- Both ECBC and model building bye-laws make use of RE mandatory for certain types of buildings, though the RE mandates remain small in comparison to the overall energy consumption of the building. Although both ECBC and model building bylaws mandate RE, there is a lack of coherence between the two. As seen from the above table, the ECBC guidelines focus mainly on solar water heating applications and energy efficiency measures mostly for commercial buildings, whereas the model building bylaws allow for use of other RE systems as well.
- Green Building Rating systems:
 - o While use of RE is mandatory in certain types of buildings in GRIHA, RE integration in buildings is not mandatory in IGBC rating systems. However, there are credit points for RE integration.
 - o There is large variation in terms of RE system size and associated points; in some cases it is based on installed capacity and in other cases it is based on energy generation.

2 : Technologies, Business Models and Case Studies

2.1 RE Technologies

A few renewable energy technologies are suitable for use in buildings. Technologies like solar PV and solar water heating have been used and accepted widely across buildings. Technologies like on-site wind generation and geothermal energy (heating/cooling) have been used in some buildings, but the application has been restricted due to limited resource availability or high costs of RE integration in buildings.

In the present study, technologies that have relatively higher probability of use in Indian buildings have been considered. These are:

1. Solar photovoltaic technologies for electricity generation
2. Solar thermal technologies for end-use applications of water heating, cooling and cooking (Table 2)
3. Heat pumps
4. Waste to energy systems (Biogas plants)

Table 2: Application of solar thermal technologies in buildings

Solar Thermal Technologies	Applications/End Use	Types of Buildings
Solar water heaters	Water heating for bathing, cleaning, laundry, etc.	Residential, Hotels, Institutions
Concentrated solar thermal technologies	Steam generation for cooking or other utilities like laundry, etc.	Institutions, Hotels
Solar water heaters, Concentrated solar thermal technologies	Hot water/steam generation for space cooling	Commercial buildings (hotels, hospitals, offices), Institutions

2.1.1 Solar photovoltaic technologies

Solar photovoltaic (PV) technology enables direct conversion of sunlight into electricity. Photovoltaic cells, commonly known as solar cells, are used to convert light (photon) into electricity. There are three types of solar cell technologies in the market, namely mono-crystalline, poly-crystalline and thin films. The output of the solar PV system varies based on the type of solar cells. Mono-crystalline and poly-crystalline cells generally have higher efficiency than thin film cells and require less roof area for the same system capacity.

The output of the solar PV system is integrated in buildings in four types of configurations as per building loads and operations. The details of these configurations are given in the Annexure 2.1. In addition to roof top solar PV systems, a solar PV system can be installed as building-integrated photovoltaics

(BIPV). With BIPV, photovoltaic material replaces parts of the building envelope, such as the wall, roof, skylights, or facades. These can be incorporated into the construction of new buildings and retrofitted to existing buildings, and help achieving higher RE share in the overall building energy consumption. However, at present BIPV is more expensive compared to the roof top solar PV systems since the bulk of the savings on a BIPV arise from reduced mounting structures and offsetting traditional building materials. BIPV prices could reduce over time as market adoption increases.

Photovoltaic thermal hybrid solar collector:

These systems are sometimes also called hybrid PV/T systems. A hybrid system/panel combines the abilities of a solar panel and air heater. This allows a single panel to generate electricity and provide water heating through the same panel. Although this appears to be an effective method and efficient space usage, currently the cost of the system makes its usage prohibitive.

2.1.2 Solar Water Heating (SWH)

A solar water heater utilises global solar radiation and provides hot water (or working fluid) at a temperature of 40–80°C. Generally, there are 3 type of technologies available in SWH systems:

1. Flat plate collector system (FPC) :

The Flat Plate Collector consists of an insulated metallic box with a toughened glass top. The metallic box contains an absorber sheet (normally made of copper) that has a selective coating to increase the absorption of solar energy. Vertical tubes made of copper, known as riser tubes, are attached to the absorber and carry the water to be heated. The riser tubes are connected to two horizontal tubes called headers, one placed at the bottom and the other at the top. The bottom header is used for flow of water into the collector, whereas the top header is used to take out the heated water.

2. Evacuated Tube Collector system (ETC):

The Evacuated Tube Collector consists of two co-axial glass tubes fused at both ends. The air between the tubes is evacuated to create vacuum that works as insulation. The outer surface of the inner tube forms the collector area and is selectively coated to increase the absorption of solar energy.

3. Evacuated tube heat pipe system:

In this type of evacuated tube, there is a pipe (usually made of copper) filled with a fluid of low boiling point. When the pipe is heated by the sun, the fluid boils and rises in the pipe due to the thermo-siphon effect. At the top, there is a connection of this heat pipe to a header pipe where this heat is transferred to the water flowing through the header pipe. The fluid in the heat pipe condenses on cooling and flows back to the bottom of the heat pipe. The SWH systems is primarily used in buildings for bathing and then for washing clothes and cleaning utensils. The details of SWH system integration in the buildings are given in Annexure 2.2.

2.1.3 Solar air conditioning

Solar air conditioning technology provides for an air conditioning (cooling) system to use solar power (passive solar, solar thermal or photovoltaic) sources to power the compressor. Solar air conditioning process can be classified in two categories, namely solar electric cooling systems and solar thermal cooling systems.

Solar electric cooling systems :

In solar electric cooling system, solar energy is absorbed and converted into direct current (DC) by a solar PV panel. This DC supply is then either used directly or converted into alternating current (AC) to run the compressor of a vapour compression system.

Solar thermal cooling systems:

Solar thermal cooling systems usually use concentrating solar collectors and absorption chillers. Solar concentrators are used to generate high pressure and temperate fluid which in turn is supplied to vapour absorption chillers. Absorption chillers use this solar-heated fluid to drive the refrigeration process.

The vapour absorption chillers²¹ could be classified as single effect, double effect and triple effect absorption chillers. The efficiency of triple effect chillers is the highest. A comparison of these systems is presented in the Table 3.

Table 3: Comparison of absorption chiller technologies²²

System	Operating temperature (°C)		Working fluid	Cooling capacity ton	COP
	Heat source	Chilled water			
Single effect	80 - 110	5 - 10	LiBr / Water	10 - 100	0.5 - 0.7
Double effect	120 - 150	5 - 10	LiBr / Water	Up to 1000	0.8 - 1.2
Triple effect	200 - 230	5 - 10	LiBr / Water	N/A	1.4 - 1.5

It can be seen from Table 3 that the higher the heat source temperature, the higher is the Coefficient of Performance (COP). The selection of solar concentrating technology depends on absorption chiller heat source requirements. The comparison of commercially available solar concentrator technologies is given Table 4.

Table 4: Comparison of solar concentrator technologies²³

Motion	Concentrator type	Absorber type	Concentration ratio ²⁴	Output temperature range (°C)
Single-axis tracking	Linear Fresnel reflector (LFR)	Tubular	10 – 40	60 – 250
	Parabolic trough collector (PTC)	Tubular	15 – 45	60 – 300
	Cylindrical trough collector (CTC)	Tubular	10 – 50	60 – 300
Two-axes tracking	Parabolic dish reflector (PDR)	Point	100 – 1000	100 – 500
	Heliostat field collector (HFC)	Point	100 – 1500	150 – 2000

21. P. Srihirin et al. 2001 — A review of absorption refrigeration technologies

22. P. Srihirin et al. 2001 — A review of absorption refrigeration technologies

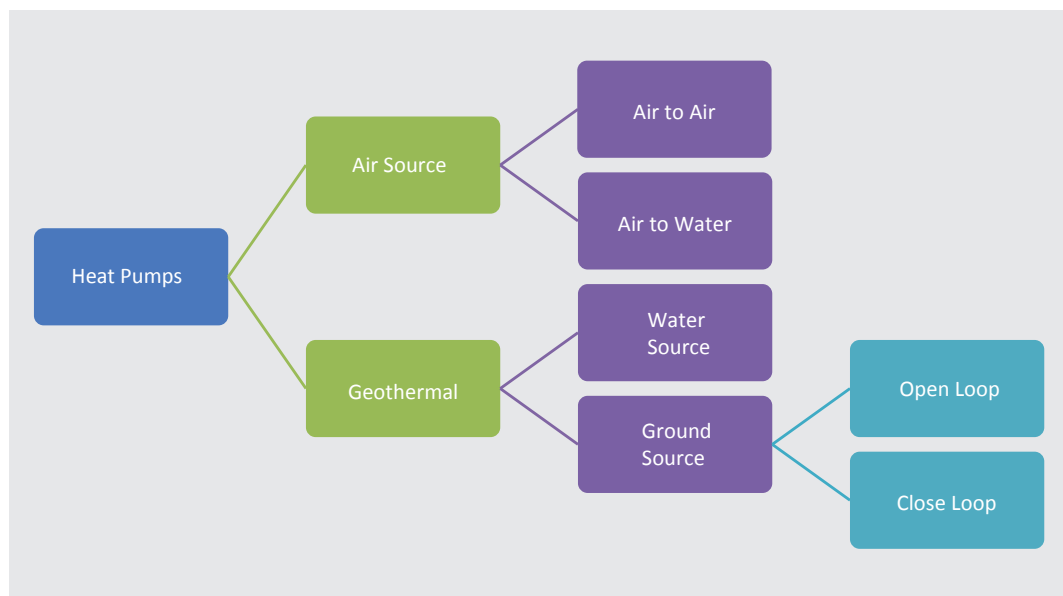
23. S.A. Kalogirou et al. 2004 — Solar thermal collectors and applications

24. Concentration ratio is defined as the aperture area divided by the receiver/absorber area of the collector

2.1.4 Heat pumps

A heat pump is an electrical device that extracts heat from one place and transfers it to another. Heat pumps can be used for both cooling (e.g. refrigerator, air-conditioner) and heating (e.g. heat pumps for water heating, space heating) applications. A heat pump is a well-known and proven energy efficient technology for generating hot water or hot air. Heat pumps are of three types, namely air source, water source and ground source (Figure 8). Air-to-air and air-to-water are the two variations of technologies that come under air source heat pumps. Of these, air-to-water heat pumps are commonly used for water heating, unlike air-to-air heat pumps, which can be used for space heating. Geothermal heat pumps although more efficient (with a higher Coefficient of Performance) in comparison to air source heat pumps, are much costlier. However, ground source heat pumps have a greater life span of 25 years in contrast to the 10 to 15 years span of air source and water source heat pumps.²⁵

Figure 8: Classification of heat pumps



Some stakeholders from the manufacturing industry and commercial consumers have suggested that India has seen a rise in the use of air source heat pumps for residential and commercial buildings, however there is no available data repository to validate the same. Ground source heat pumps and water source heat pumps can work with high efficiency in moderate to extreme hot and cold temperature conditions, unlike air source heat pumps which work more efficiently in moderate temperature conditions. However, despite the variability in Indian climatic conditions that range from moderate to extreme heat and cold in various parts of the country, air source heat pumps have the highest market share amongst various types of heat pumps. A comparison of air source heat pumps with conventional water heating systems is presented in the Table 5.

25. Ruqun WU 2009 , Energy Efficiency Technologies, Air Source Heat Pump vs. Ground Source Heat Pump

Table 5 : Comparison of air source heat pumps and convention water heating systems

Parameter	Air heat pump	Gas water heater		Oil water heater	Electric water heater
Input energy	Electricity	NG	LPG	HSD	Electricity
Heating demand (kcal)	7000	7000	7000	7000	7000
Heating value	860 kcal/kWh	8600 kcal/Nm ³	11200 kcal/Nm ³	10200 kcal/kg	860 kcal/kWh
Efficiency (assumed)	340%	87%	87%	87%	95%
Energy consumption per day	2.4 kWh	0.94 m ³	0.7 kg	0.8 L	8.6 kWh
Cost (Rs. per unit - assumed)	8	55	85	60	8
Cost per day (Rs.)	19	51	61	47	69
Annual cost (Rs.)	6990	18782	22288	17275	25018

Note: Heating demand calculated for 200 L water heated from 15°C to 55°C

2.1.5 Waste to energy technologies

Large quantities of organic waste is generated in residential complexes, restaurants, hotels, hostels, industrial canteens, etc. This organic waste generated in buildings can be utilised using bio-methanation technologies. The organic waste is converted into bio gas which can then be used either for producing heat or electricity (by using it in an engine). While in case of industrial canteens and restaurants, it is possible to use biogas for cooking applications, in case of large residential complexes it may be more practical to use biogas for generating electricity, which in turn can be used for the operation of common services like corridor and outdoor lighting, water pumping, etc. The application of bio-methanation technologies not only help in producing onsite renewable energy, but also help in decentralised waste management, and therefore reduce the burden on city-level waste management systems.

2.2 Business Models

Many new and innovative business models support increased deployment of RE technology in buildings, and may be categorised into three main types (Figure 9).

Figure 9: Different types of business models²⁶

CAPEX or End-user Owned	OPEX or Third party owned & operated	Utility-Owned
<ul style="list-style-type: none"> End user invests in RE system Energy generated is either used for internal consumption or exported to grid Financing for the system from banks / financial institutions Design and deployment by system integrators 	<ul style="list-style-type: none"> Third Party (e.g. RESCO) makes the investments, installation & responsible for O&M No investment and hassle free for end-user Agreement between third party and end-user on electricity generated (e.g. PPA for rooftop SPV) Supports lower cost financing, scale, technical expertise & efficient operation 	<ul style="list-style-type: none"> Investment by utility Emerging business model – mostly in developed countries for rooftop solar PV RE System becomes an integral part of the electricity supply and distribution infrastructure
CAPEX-OPEX model Similar to OPEX; end user invests and can avail depreciation benefits		

26. MNRE/USAID/GERMI report on "Best practices manual for implementation of state level rooftop solar photovoltaic programme in India", June 2016

2.2.1 CAPEX or end-user owned

This is the first-generation business model, where the building owner/user is responsible for the investment in the RE system. This investment could be 100% equity or a combination of debt (through banks / financial institutions) and equity. The energy generated by the RE system can either be used for self-consumption or export (e.g. net-metering with a solar PV system) to reduce energy bills or to generate revenue. The design and the deployment of the RE system is implemented by RE system integrators.

2.2.2 OPEX or third party owned and operated

This is the second-generation model, where a third party (e.g. RESCO) makes capital investments for the RE system, installs it and is also responsible for its operation and maintenance. The model is becoming popular in India as it addresses the key barriers of 'high capital cost' and 'performance apprehensions' of the RE system, and reduces the risks of the building owner. Third party can make the investment as 100% equity or a combination of debt (through banks / financial institutions) and equity. The model allows the third party to bring in lower cost financing, scale, technical expertise and efficient operation. The revenue/saving from the RE is shared by the third party and building owner/user which is done through an agreement between the third party and the building owner/user (e.g. PPA for rooftop SPV).

2.2.3 Utility owned

This is an emerging business model, mostly in developed countries for rooftop solar PV system. Here the investment is made by the utility through procurement contracts / direct investment on customer's roof or financing support. PV becomes an integral part of the electricity supply and distribution infrastructure. The ownership, operation and maintenance of the RE system is carried out by the utility.

2.3 Case Studies

A few buildings with different typologies were studied to understand the several factors that contribute to successful integration of RE technologies and also understand their impact on overall energy consumption of the buildings. The following table enlists the case studies in brief.

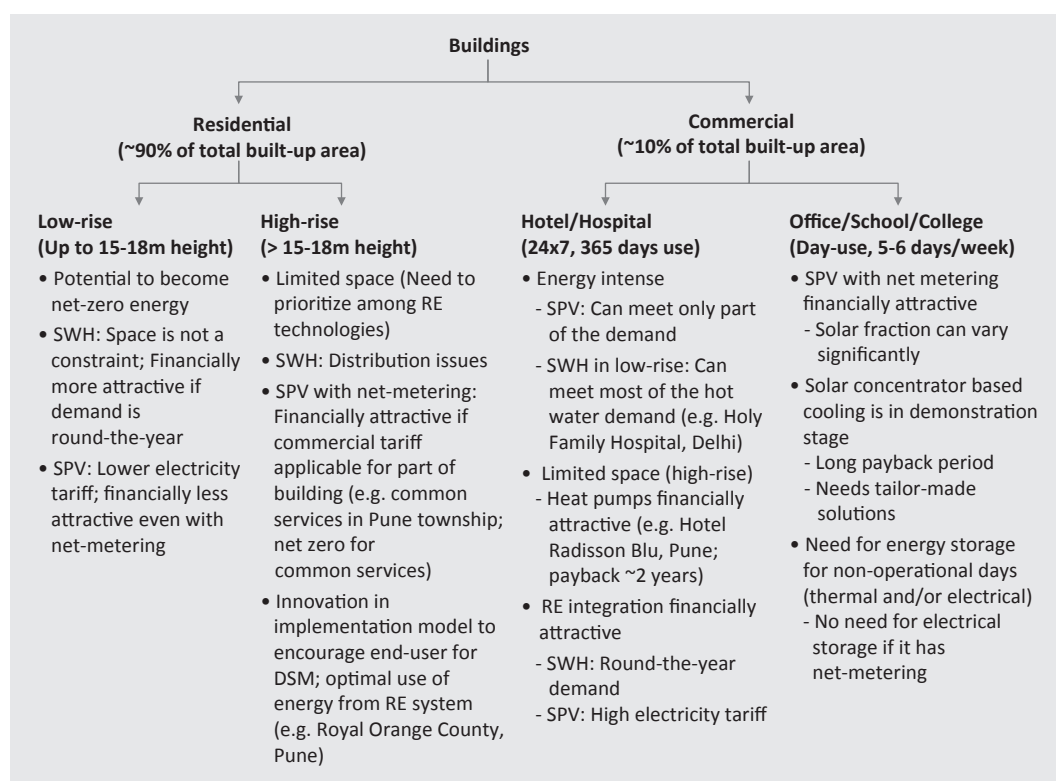
Table 6: Details of various case studies

S. No	Building Name	Building Typology	RE System	Ownership/Business Model
1	Residential building - Najafgarh, Delhi	Residential — 3 storey (low-rise)	Roof top Solar PV (2 kW _p , future plan to expand it to 5 kW _p)	Self-owned
2	Magarpatta City, Pune	Residential — high-rise township	Solar Water Heater (8240 collectors, 10,30,000 LPD)	Self-owned; Cost included in the flat price Maintenance by Magarpatta City Management

3	Royal Orange County, Pune	Residential high-rise apartments	- Solar water heater (SWH): 6500 LPD - Solar Photovoltaic (PV): 20 kW _p (additional electricity supply)	Self-owned; Cost included in the overall building cost 5 year operation of SPV system by building developer
4	Lunkad Sky Lounge Society, Pune	Residential high-rise apartments	Roof top Solar PV - 12 kW _p	Renewable Energy Service Company (RESCO) model Power Purchase Agreement (PPA): 20 years @0.8 x Electricity tariff
5	Indian Habitat Centre, New Delhi	Commercial — Office, High-rise, Multi-tenant/owner	Roof top Solar PV (250 kW _p)	RESCO model PPA: 25 years Unit cost: Rs. 5 per unit (Constant)
6	Aranya Bhawan, Jaipur	Commercial — Public Office (Daytime operation)	Roof top Solar PV (45 kW _p)	Self-owned
7	NTPC Energy Technology Research Alliance, Noida	Commercial — Office + Workshop (low-rise)	-Solar concentrator based cooling: 40 TR; retrofitted; not integrated with conventional HVAC system -Solar PV: 80 kW _p	Solar Cooling: Self-owned Solar PV: Self-owned (30% subsidy from MNRE) Internal R&D
8	Radisson Blu, Pune	Commercial — Hotel (high-rise)	Heat pump (air source) Capacity: 40 TR	Build Own Operate Transfer (BOOT) model — 15 months
9	Holy Family Hospital, New Delhi	Commercial — Hospital (low-rise)	Solar water heater (200 m ² ; 10,000 LPD)	RESCO model: 7 years' contract - Agreement: 51000 - gas bill (paid to RESCO operator) - Now self-owned
10	Thyssenkrupp Industries Ltd., Pune	Industrial	Biogas (250 kg/d of waste) Generation: 30–32 m ³ /day	Self-owned, O&M with developer

Out of ten case studies, four are from the residential sector, five from the commercial sector, while one is from the industrial sector. These case studies include six installations of SPV, three installations of SWH, and one installation each of solar concentrator, heat pump and biogas. Some of the case studies have multiple RE systems installed. Key observations and findings of these case studies are listed in Figure 10 below and explained in subsequent sections. Detailed information on all case studies is given in Annexure 1.

Figure 10: Key observations and findings of case studies



2.3.1 Influence of building typologies on RE potential and economics

Parameters like energy demand, energy usage pattern, roof space availability, and applicable electricity tariff varies significantly with building typologies. Therefore, the potential and the economics of the RE system varies with building typologies. For example, an energy efficient, low-rise residential building with lower energy demand and sufficient space available for an RE system has the potential to become a net/near zero energy building. Although, lower electricity tariffs for residential consumers lead to less attractive economics of the RE system. On the other hand, for a high-rise commercial building, electricity tariffs are higher, making the RE system financially more attractive. However, due to limited space and the high energy demand, only a small part of the total demand can be met through an RE system.

It is estimated that almost 90% of the total built-up area of the country will be for residential buildings and hence the roof area available on residential buildings is much higher compared to commercial buildings. However, because of lower electricity tariffs, economics of roof top SPV systems is less attractive, even with net-metering. Though, capital subsidies for residential consumers, presently available from the Ministry of New and Renewable Energy (MNRE), can help make it more viable.

2.3.2 Need for innovative implementation models

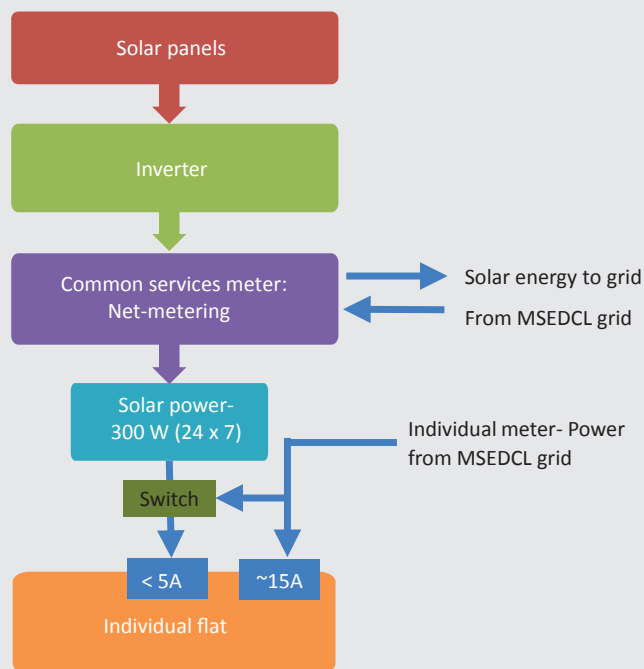
Different types of building typologies and ownership patterns require different types of innovative business and implementation models for exploiting the full potential of RE integration in buildings. The example, an innovative implementation model for a high-rise, multiple-ownership residential building, is explained in Box 1. This model also promotes energy conservation and demand side management.

Box 1 :

Example of an innovative implementation model that incentivises electricity conservation and demand side management

Royal Orange County, Pune is a residential building complex of 9–12 storey high buildings with 2 and 3 BHK homes. A 20 kW_p SPV system (and 104 m² of SWH also) has been installed on one of the towers, which is 11 storey high and has 44 flats. All flats have been given dual electricity supply: one from the SPV system and other from the electricity grid (Figure 11).

Figure 11 : Schematic of electricity supply and SPV system at Orange County, Pune



The supply from the SPV system per flat is limited to 300 W. At any point in time when the household electricity demand remains below 300 W, the electricity can be supplied from the SPV system. The solar electricity is free for building occupants. Once household demand goes above 300 W, the electricity supply switches from the SPV system to the electricity grid, and electricity is charged to the end-user at the applicable utility tariff. The end-user can observe if they are getting electricity from the SPV or the electricity grid. With this arrangement, end-users always try to maintain their electrical load below 300 W, by minimising wastage of electricity and managing their electricity usage pattern. This also make the end-user aware of the energy usage and gives them a good incentive (minimum electricity bill to be paid if demand remains below 300 W) to use electricity consciously.

2.3.3 Using RE for meeting hot water demand in hotels and hospitals

The commercial viability of RE technologies like SWH and heat pumps is higher in case of commercial buildings such as hotels and hospitals which have round-the-year hot water demand, and have higher electricity tariff or use costly petroleum fuels like diesel for water heating. For low-rise commercial buildings where

sufficient roof space is available, the SWH system can meet most of the hot water demand (Box 2 – Holy Family Hospital). For high-rise buildings where the space is limited, heat pumps (Box 2 – Radisson Blu) or a combination of an SWH and a heat pump can meet the hot water demand.

Box 2 :

SWH for commercial building having round-the-year hot water demand

Holy family hospital (HFH), New Delhi is a 332 bedded multi-specialty hospital, having hot water demand round-the-year. A 200 m² of SWH system (Figure 12) has been installed on the rooftop with backup heating by gas boilers, to meet the hot water demand. SWH system was installed under RESCO model and handed over to HFH after completion of 7 years of contract with RESCO. HFH could save 40% of water heating expenses during RESCO contract period and could also retain SWH system after completion of contract. Based on information shared, it is estimated that ~80% of the hot water demand is being met by the SWH system.



Figure 12 : SWH system at Holy Family Hospital



Figure 13 : Heat pump and Radisson Blu Hotel

Similarly, in case of Radisson Blu hotel, Pune (5 storey building with 220 rooms), the hot water demand remains round-the-year, the area on the rooftop was not available for SWH system installation. An air source heat pump of 40 TR (138.4 kW) capacity has been installed (Figure 13) to meet the hot water demand for bathing and kitchen applications. The space needed for heat pump (excluding storage tank) is only ~2 m². Since, it runs on electricity therefore no backup heating is needed and it consumes 3-4 times less electricity as compared to electric (resistive) heaters.

2.3.4 Key role of third party ownership RESCO model

Third party ownership (OPEX) model (e.g. RESCO model) is key to overcome two major barriers: high capital cost and uncertainty/doubt in RE technology performance. The case-studies covered four projects that were done under the RESCO model (Box 3). From the end-user perspective, it is almost zero risk and zero investment, and they can get energy at a lower cost as compared to conventional sources. For the end-user, this also eliminates the burden of O&M of the RE system. However, for a third-party owner (RESCO), raising finances for investing in projects is difficult, which limits their ability to undertake multiple projects.

Box 3 :

OPEX model a key for RE system installation up-scaling

Out of ten case studies, four (Lunkad Sky Lounge Society Pune, Indian Habitat Centre New Delhi, Radisson Blu Pune and Holy Family Hospital New Delhi) follow the RESCO model. In all four cases, the end-user did not have to invest any capital cost for the installation of the RE system and they could save their energy cost from day one of the installation. Also, the operation and maintenance of the system is done by third party (RESCO) which makes this model more attractive for the end-user.

These case studies cover residential, office, hotel and hospital buildings and include SPV, SWH and heat pump technologies. This suggests that the OPEX model can play a major role in up scaling of RE system installations.

2.3.5 Importance of fully functional net-metering regime

Net-metering arrangements (Box 4) help the end-user to overcome the additional cost and maintenance related to energy storage in electric batteries and eliminates wastage of energy generated during non-operational days. Hence, net-metering improves the economics of solar PV systems.

Box 4:

Net-metering could be a big boost for roof top SPV system installation

One of the key challenges for SPV systems remains the electricity storage which is usually set up with batteries. In case of locations where the availability of grid electricity is good, opting for net-metering not only improves the techno-economic feasibility of the system but also reduces the operation and maintenance cost (replacement of batteries).

Figure 14: SPV system at Aranya Bhawan, Jaipur and its schematic



Aranya Bhawan, Jaipur has a 45 kW_p SPV system with a net-metering system (Figure 14). Initially, a 26 kW_p system was installed without net-metering and energy storage. Hence, they were not able to utilise the energy generated during weekends and holidays, and almost 30% of the SPV generated energy was being wasted. After the capacity addition and net-metering arrangement was in place, they could fully utilise the SPV generated electricity. During weekdays, the electricity is consumed within the building, while during the weekends/holidays, the electricity is exported to the grid and they pay only for the net electricity (electricity taken from the grid – electricity exported to the grid) consumed. It is estimated that ~20% of the annual electricity requirement of the building would be met by the SPV system.

Lunkad Sky Lounge Society, Pune which is a residential high-rise apartment building, also has an SPV system installed in RESCO mode with similar benefits.

2.3.6 Importance of planning RE integration during building design and benefits of planned maintenance

Planning RE integration with building construction ensures optimal implementation and operation of the RE system and reduces its cost. An example of a small scale PV system installed during the construction at a household (Najafgarh house) helped the end-user to get all the electricity required (water pumping and lighting) during the house construction from the solar PV system and helped meet part of the energy demand post construction (Please see Annexure 1 for detailed information). Similarly, in a large township (Magarpatta City, Pune; Box 5), installation of SWH system during the construction ensured that all households got hot water from RE by paying a small additional amount during house purchase.

Box 5:**RE system (particularly SWH) integration during construction stage and having a proper maintenance arrangement gives optimal results**

Magarpatta city, Pune is large township (~600 acre of land) which has residential and commercial buildings. All the households in this township have a provision of hot water system through SWH system (Figure 15). A total of 8240 solar hot water panels were installed in the entire township till date, having a solar collector area of 16,480 m². Individual the SWH system was provided with individual housing while a centralised SWH systems was provided in a multi-storey building (one system for each wing of tower).

Figure 15: SWH system at Magarpatta city, Pune



But the most important thing is that SWH system integration was planned during the construction stage itself. Purchasers of houses had to pay only a small additional upfront cost for the SWH system. All the bathrooms of the flats were provided with solar hot water connections with all the piping work done during the building construction. This ensured proper integration of the SWH system, which ensured proper operation of the system and reduced maintenance requirement. Further, the Magarpatta city property management is carrying out the operation and maintenance for the SWH system, and hence ownership of SWH is totally hassle free for the house owners. A few of the residents we talked to were very happy with the performance of the SWH system, and it is estimated that ~80% of their hot water demand is being met by the SWH system.

2.3.7 Prioritising between Solar Photovoltaic (SPV) and Solar Water Heating (SWH)

As buildings become taller, space availability on the roof has increasingly become a limiting factor for RE system capacity. A common point of debate is related to the choice of technology best suited to make maximum benefit of the available space. Typically the debate is focused on deciding whether to install an SWH or SPV system or a combination of both. More often, SWH systems have received priority in installations as many urban local bodies have been supporting and mandating the installations of SWH systems for over a decade, whereas subsidies and schemes for solar roof top PV have entered the markets very recently. Case studies for buildings which have year-round hot water demand (≥ 9 months) show that these

systems have a shorted payback period for SWH systems. This has been observed in two case studies (Residential: Orange County, Pune and Hospital: Holy Family Hospital, Delhi) where the roof area was first utilised for SWH system installation to meet the hot water demand, and the remaining area was later used for SPV system installation. With newer technology there are two technology options that can be used to address this concern. Using a solar PV system for electricity generation in combination with air source heat pumps for water heating can be an efficient space utilisation strategy. Also, the new solar hybrid panel technology can support water heating and electricity generation in the same available space.

3 : Policy/Regulatory Environment for RE in India

Almost 40% of the total energy today is utilised by the building sector and it is set to rise rapidly as the building stock in India grows by leaps and bounds each year. The innovative applications and business models discussed above show that using renewable energy in retrofit mode and design stage can help in significantly reducing the energy demand of buildings. These RE integration practices in buildings emphasise that not only does RE integration in buildings provide long term savings but also that it enhances a comfortable living experience.

The Government of India has a target of 40,000 MW of solar rooftop PV capacity to be installed by 2022, and as on September 2016, only 1020 MWs²⁷ of solar rooftop PV systems have been installed. Similarly, the targeted solar water heater installation is 20 million sq. m. of which 11 million sq. m. have been installed by 2016. Several national and state/local policies today require that greater amounts of energy are generated using a renewable energy source; the various targets set by the Government of India, building codes and green building rating systems are a step forward in this direction. According to the recent U.S. Green Building Council Report²⁸, India has approximately 15.90 million gross square meters of space certified to LEED of a total 644 projects. The other two major green building rating systems, IGBC and GRIHA, also have large areas of buildings certified. The following chapter discusses the policy and regulatory framework that support RE integration in buildings and highlights barriers or constraints in full scale RE integration in buildings.

3.1 Central Government/State Policy and Regulatory Framework for RE Technologies

Most of the policies/programmes which promote RE technology use in buildings have focused on solar water heating and in the recent years on solar roof top PV integration. A few other technologies that have the potential to be readily integrated in buildings to offset energy consumption have not had as much policy-regulatory attention for a variety of reasons including high costs, lack of awareness, etc. The following section details the policy-regulatory framework for some of the RE technologies being used in buildings.

3.1.1 Solar water heaters

MNRE, state and municipal governments have tried three types of policies to promote integration of solar water heaters into buildings.

27. BTI Solar Rooftop Map 2016: <http://www.bridgetoindia.com/reports/india-solar-rooftop-map-2016-edition-2/>

28. <http://www.usgbc.org/articles/usgbc-announces-international-ranking-top-10-countries-leed>

3.1.1.1 Capital subsidies

For a long time, one of the major incentives for installing SWH was a capital subsidy from the MNRE. The capital subsidy was introduced in the 1990s but was discontinued towards the end of the decade. It was again reintroduced with the launch of the Jawaharlal Nehru National Solar Mission (JNNSM) in 2010, however, it was again discontinued from October 2014.

3.1.1.2 Building bylaws for mandatory use of solar water heaters in buildings

The Ministry of Urban Development had issued a government order and model building bylaws in 1999 for mandatory installation of solar water heaters in certain types of buildings. The buildings covered were hotels, hospitals, hostels, rest houses, canteens, residential institutes, and residential housing. Since then, around 20–25 state/UTs have issued notification in this regard, and around 100 municipal corporations and urban local bodies have incorporated the mandatory use of SWHs in their building bylaws. However, except for a few cities, its implementation has not been as effective as desired because of multiple reasons such as:

- Limited technical know-how of SWHs among the Urban Local Bodies (ULB) officials who were responsible for the implementation of the regulation
- Absence of technical guidelines for ULB officials on SWH system sizing and their installation for different categories of buildings which at many places resulted in installation of under-sized systems or poor quality installation
- The end-users not being convinced about the utility of SWH in regions or building types, where the hot water demand is limited, e.g. residential buildings in some of the northern states where the hot water demand is only during few winter months and during these months, due to fog, available solar insolation is less which puts a question mark on the utility of SWH systems

There are some examples of success in cities such as Bengaluru, Pune and Rajkot where there is a demand for hot water for a large part of the year and implementation has been quite effective. The success can be attributed to factors such as active role of ULBs (mandatory regulations as well as promotions and incentives), high level of user appreciation and awareness, strong SWHs supply and after sales service chain, and the presence of a good number of reference installations in various types of buildings. Recently, the Ministry of Urban Development issued model building bylaws 2016, in which both Solar PV as well as SWH systems have been mandatory in various types of buildings. The new building bylaws do not address the issue of choice between SWH and Solar PV systems in buildings having limited roof availability for installation of both the RE systems.

3.1.1.3 Rebate in electricity bill for installation of SWHs

In an effort to reduce the peak demand load in the electricity grid, particularly during the winter mornings when geysers in all the buildings are simultaneously switched on, electricity distribution companies in some of the states/cities (e.g. Rajasthan, Uttarakhand, Bengaluru, etc.) are offering rebates in electricity bill for installation of SWHs. For example, in Karnataka, a rebate of Rs. 0.50 is being extended in the electricity bills per unit of consumption subject to a maximum of Rs. 50, and in Rajasthan the scheme allows every SWH user to receive a rebate on their electricity bill of Rs. 0.25/kWh, capped at a maximum of Rs. 300 per month independent of the age of the system.

3.1.1.4 Rebate in property tax for installation of SWHs

Although the central government subsidy for solar water heaters has been discontinued since 2014, several urban local bodies (ULBs) continue to incentivise installation of solar water heaters, by providing a rebate in property tax to housing societies and individual property owners who have installed SWH systems. Several ULBs including Pune, Thane, Mumbai, Nagpur, Rajkot, Chandigarh, Delhi, and Bengaluru provide a 5–10 % of property tax rebate for consumer premises where solar water heater systems have been installed.

3.1.2 Solar Rooftop PV

3.1.2.1 Government subsidies

The Ministry is implementing a 'Grid Connected Roof Top and Small Solar Power Plants Programme'²⁹ in which the solar roof top plants with capacities between 1 kW_p and 500 kW_p are entitled to Central Finance Assistance (CFA) of 30% of the benchmark cost for residential, institutional, government and social sector buildings. Besides CFA, the Government of India also provides several fiscal benefits to grid-connected roof top and small power plants, including accelerated depreciation for industrial and commercial buildings, customs and excise duty exemptions, 10 years' tax holiday, low interest rate loans from the Indian Renewable Energy Development Agency (IREDA), priority sector lending for loans on renewable energy projects, and home improvement loans to include solar roof top installations.

Incentive Scheme for Government Buildings

For government entities including PSUs, the MNRE has promulgated an 'achievement-linked incentive and awards scheme' instead. This scheme allows for all government buildings to claim for an incentive on every KW of solar installation under the scheme.³⁰

3.1.2.2 Net-metering regulations

Net-metering is a billing mechanism which allows energy banking and credit for excess solar electricity fed into the distribution grid by the project. At the end of the billing period, the consumer need to pay for the 'net' electricity consumed (difference between electricity consumed from the grid and the electricity fed into the grid from the solar project). If the amount of electricity fed into the grid is more than that consumed from the grid, the excess is carried forward to the next billing period. This has proved a crucial incentive for consumers to adopt rooftop photovoltaic (RTPV) systems and now 35 states have some form of net-metering system in place.³¹ Table 7 gives the details on net-metering in some sample states.

29. <http://mnre.gov.in/file-manager/UserFiles/CFA-Solar-Rooftop-03082015.pdf>

30. <http://mnre.gov.in/file-manager/UserFiles/Notification-Incentive-&-Award-scheme-for-Govt-Sector-30032017.pdf>

31. India Solar Rooftop Map 2016 Edition, <http://www.bridgetoindia.com/reports/>

Table 7 : Net-metering regulations in some states

Net-metering Regulations	Cumulative capacity allowed at distribution transformer (% of capacity)	Minimum - Maximum Capacity (RTPV system level)	Metering and inter-connection costs borne by	Settlement or banking period	Billing period	Units bought by DISCOM at the end of settlement period	Rate at which excess injected energy bought by DISCOM
Maharashtra (Sep 2015)	40%	up to 1 MW	DISCOM	April – March	Monthly	All surplus	APPC
Gujarat (Jun 2016)	65%	1 kW – 1 MW (maximum up to 50% of consumer's sanctioned load)	Consumer	1 billing cycle	Monthly	Not mentioned	Fixed APPC for whole life of system (for all non-obligated consumers). 85% of APPC for C&I obligated consumers
Rajasthan (Feb 2015)	30%	1 kW – 1 MW (maximum up to 80% of consumer's sanctioned load)	Consumer	Not mentioned	Monthly	All electricity excess injected, if > 50 kWh/month	ERC determined FIT
Tamil Nadu (Nov 2013)	30%		Consumer	August – July	Monthly - Domestic; Bimonthly -Industrial	All energy injected up to a max of 90% of consumption during settlement period	Not mentioned

Source : Prayas analysis based on various state net-metering regulations.

Note : Except for Gujarat and Rajasthan, all states allow for carry forward of excess generation to next billing cycle. Gujarat allows none, while Rajasthan allows only up to 50 units/month. Kerala allows its DISCOM to recover metering costs from the consumers (as decided by the ERC).

The net-metering regulations of almost two-thirds of the states allow for rooftop systems up to a cumulative Distribution Transformer (DT) capacity of 15–30%. Gujarat, however, has allowed a much higher limit of 65% of rated DT capacity, indicative of the state's eagerness to ensure wide acceptance and use of this mechanism. Madhya Pradesh and Haryana allow a maximum of 10 MW and 200 MW respectively as the cumulative solar roof top capacity for each DISCOM. More than half of the states allow for roof top systems with capacity ranging from 1 kW_p to 1MW_p, barring Delhi, which has only defined a minimum capacity of 1 kW_p. All states have allowed solar generation to qualify for meeting the Distribution Licensee's renewable purchase obligation (RPO) targets in case the consumer is not an obligated entity.

Haryana introduced a novel way of incentivising those opting for net metering. In the first amendment to its regulations, dated July 2015, Haryana introduced an incentive of Rs. 0.25/kWh for every unit of solar energy generated by the system owner in a billing cycle which can offset billing of additional consumption. Delhi gives an additional incentive of Rs. 2/kWh as a Generation Based Incentive (GBI) for domestic roof top installation from January 2016 to December 2018. Kerala allows for a form of aggregate net-metering by permitting consumers to offset excess solar electricity from one system against consumption at some other premises by paying 5% of energy as wheeling charges.

The MNRE has also managed to get a substantial increase in the overall allocation for roof top capital subsidies at Rs. 5,000 crores for 2015–2020. Apart from the capital subsidy, the MNRE has facilitated RTPV adoption through other financial incentives as well. These include mandating banks to provide loans for roof top solar as part of home loans, concessional interest rates from the IREDA for system aggregators, and loans under priority sector lending status.

The GoI is aggressively pushing all government departments and ministries to adopt roof top solar and lead by example in contributing to the 40 GW national target. The MNRE has collated data from up to 50 ministries/departments, which shows that nearly 5.9 GW of solar potential exists on their building roof tops and surplus areas available to them. This could help them save nearly Rs. 830 crores annually.³² However, DISCOMs have not been particularly supportive of operationalising 'net-metering', especially for commercial and industrial consumers. They have expressed apprehensions about roof top solar systems on two fronts. Firstly, they are concerned about the cumulative impact of a large number of rooftop systems on the distribution grid, in terms of reliability, power quality and safety. Secondly, they are apprehensive of losing revenue from high-tariff commercial and industrial consumers.

Several Indian cities and towns are experiencing rapid growth in electricity demand. In this context the GoI has designed two programmes to exclusively encourage ULBs to support solar installations in cities. The Solar Cities Programme and the Smart City Initiative promote installation of solar and other renewable energy sources. The solar city programme is designed to support cities to reduce their projected demand of conventional energy by 10% at the end of five years, through a combination of enhancing supply from renewable energy sources (including solar, wind, biomass, small hydro, etc.) and energy efficiency measures. The Smart City initiative mandates that 10% of Smart Cities' energy requirement will be met using solar energy, and at least 80% buildings should be energy efficient and green rated buildings.

3.1.3 Biogas

To promote installation of biogas plants, the National Biogas and Manure Management Programme has been implemented since 1981–82. The objective of the programme was to provide clean biogas fuel for cooking and reduce the use of LPG. The policy provides financial assistance of Rs. 5500 to 9000 per plant

32. <http://mnre.gov.in/file-manager/UserFiles/Allocation-of-expert-PSUs-for-implementation-of-Grid-Connected-Rooftop-Solar-plants.pdf>

as per its capacity (1 m³/day to 6 m³/day), a higher subsidy (Rs. 7000 to 17000 per plant) for special areas like North-Eastern Region (NER) states, Jammu and Kashmir, etc., turnkey job fee linked warranty of plant, financial support for repair and maintenance along with training of users and staff, and publicity and awareness. This programme has been designed to support family sized biogas systems in rural and semi-urban areas.

The programme has also approved the KVIC (Khadi Village Industries Commission) gasholder type biogas plants with a capacity of one to six cubic meters per day as eligible for CFA. This has limited uptake of using biogas technology in urban areas, which can be an effective way to manage organic waste. The initial estimated potential of 12 million family type biogas plants in the country was drawn on the basis of cattle dung substrate generated. Against this a cumulative total of 4.9 million systems have been installed up to 2015-16.

A few states like Bihar, Haryana, and Gujarat have also been supporting biogas uptake by providing incentives and subsidies through different state programs.

3.1.4 Heat pumps

India is seeing a gradual uptake of heat pumps as a resource to meet the increasing water heating and air cooling demands. However, the policy environment currently only incentivises ground source heat pumps with no framework for air source heat pumps.

The MNRE came out with the Indian Geothermal Energy Development Framework, 2016 that emphasises the importance of capacity building of this form of energy. In keeping with this, the MNRE recently announced exemption from obtaining separate permissions required for drilling of Ground Source Heat Pump (GSHP) bores.

One of the goals of the framework is to mitigate the increasing demand for electricity requirement by deploying GSHPs instead of HVAC systems, and retrofitting existing HVAC systems with GSHP based systems. A demonstration grant will be provided for deployment of GSHPs on a case to case basis. The Ministry of Finance allows 40% depreciation on installation of GSHPs. The criterion for CFA eligibility for standalone GSHP systems is that the system should achieve a minimum of 30% savings of electricity in comparison to the conventional HVAC systems. Subsidy of 30% and 25% for closed loop and open loop type GSHP systems respectively is offered.

3.2 Hurdles and challenges to deployment at scale

The use of renewable energy systems in buildings is acting as a demonstration of the scope for leadership in sustainability, energy conservation, resource conservation, reliability of on-site renewable energy generating systems, and allied benefits. As policies, regulations and incentives such as the ones mentioned above are enacted, the barriers for renewable energy integration in buildings are being reduced. However, certain challenges and hurdles still prevent the installation of renewable energy systems on a large scale.

Lack of Information

Insufficient information on correct methods and technologies for renewable energy systems integration in buildings has been preventing large scale deployments over the years. A clear knowledge gap between interests of developers, architects, building managers, tenants and others from the beginning prevent right amount of investments required to impact building design, RE ready infrastructure and evaluation of costs vs. savings over time.

Small size and high financing costs

The size of available roof or land space within a building premise has always been a disincentive for buildings owned by multiple residents/tenants for installation of RE systems. Retrofitting such buildings with renewable energy systems as an energy savings measure may appear to not be a financially viable option. At the same time, including the costs of renewable energy systems as a part of the fixed capital budget by the developer who is considering to maximise energy savings across the building portfolio may appear to be a small value proposition for the extra cost and hence may not interest potential customers.

Institutional barriers

In several industrial and commercial buildings, the goal of building managers is to achieve best performance at least capital costs. Hence, the measures of energy conservation applied in these setups are limited to prescriptive methods rather than assessing alternatively available solutions including renewable energy systems which are performance based and can add to energy savings over a long duration of time.

Measuring energy performance

Currently there are no strict rules that ensure measurement of building energy performance. Ensuring strict adherence to building energy performance guidelines and codes could improve the uptake of renewable energy system integration in buildings.

Optimising building energy use for heating/cooling

Most energy demand of buildings arise from heating/cooling. Fewer policies and regulations provide support for use of energy efficient technologies that aid in meeting the heating/cooling demand of buildings, increasing the quantum of demand required to be met by using RE systems.

Barriers in scaling-up RESCO model

The Renewable Energy Service Company (RESCO) business model addresses several important barriers, such as capital expenditure, ensuring regular maintenance and operation, as well as performance of the RE systems. The information gathered during the case studies show that the model has been quite effective for certain types of buildings, e.g. commercial buildings, institutional buildings and multi-apartment residential buildings. Addressing important concerns like poor contract enforceability and preventing default by customer for older projects can support the scaling-up of the RESCO model and lead to faster deployment of RE technologies in buildings.

4 : Conclusion and way forward

In India, residential and commercial buildings accounted for ~23% and ~8%, respectively, of the total electricity consumption in the year 2014–15³³ and emitted respectively, 204.3 and 73.7 million tons of CO₂ in the same year.³⁴ Various studies³⁵, on the other hand, have also shown that the energy demand in the building sector has been consistently increasing in the past, and is expected to increase at the rate of 8%³⁶ in the coming years. Measures like energy efficiency in buildings and renewable energy integration have demonstrated the potential of helping to reduce this rise in energy demand. The present study focuses on the renewable energy integration in buildings, which can contribute significantly in reducing electricity and fossil fuel usage in buildings, thus reducing the operational energy and carbon footprint of buildings.

The focus of this report is to provide a case study based reference on building energy use, by highlighting the role of renewables in meeting the energy demand of buildings. The learnings from the case studies were corroborated in a discussion with key stakeholders through a round table discussion. The roundtable discussion was organised on 20 October 2016 in New Delhi with an aim of understating the different perspectives and challenges that exist in the sector with key stakeholders. It was attended by around 30 participants, including representatives from the Ministry of New and Renewable Energy (MNRE), NITI Aayog, Town and Country Planning Organisation, Municipal Corporation, manufacturers/suppliers of RE products, building rating agency, financial institutions and consultants working on buildings and the RE sector. The main objectives of the workshop were to share the initial findings of the study with key stakeholders and get their inputs to understand key challenges, opportunities and action points in further increasing the effective use of RE in buildings. The inputs and comments received during the discussion were analysed and have added significant value in the preparation of this report. Details of the roundtable are available at <http://prayaspune.org/peg/past-events/114-stakeholder-workshop-on-renewable-energy-onsite-generation-and-use-in-buildings.html>.

The ability of renewables to contribute to significant reduction of energy demand in buildings has been proven, yet the progress in terms of its uptake has been rather slow. A few critical areas/issues that need to be addressed in order to support RE integration uptake are discussed below.

33. Energy Statistics 2015; Ministry of Statistics and Programme Implementation, Govt. of India

34. http://cea.nic.in/reports/others/thermal/tpece/cdm_co2/user_guide_ver10.pdf

35. <http://www.cseindia.org/userfiles/Energy-and-%20buildings.pdf>

36. http://www.gbpn.org/sites/default/files/08.%20INDIA%20Baseline_TR_low.pdf

Key findings from case studies and way forward :

Building design and space constraints

- The potential and the economics of RE systems changes with building typologies, owing to varied energy demand, usage patterns, space availability and applicable electricity tariffs. There is a significant potential for making low-rise (3–5 floors) residential buildings and less energy intensive commercial buildings net-zero or near-zero energy building through the use of renewables. In case of high-rise residential and commercial buildings, limited space availability and high energy demand add a limitation to the amount of total demand that can be met through RE systems.
- In case of limited space availability for RE system installation, choice and prioritisation of RE technology needs to be based on a detailed technical and financial analysis of the alternatives that would best optimise the available space (e.g. SWH and/or solar PV system on available roof space).
- Planning RE integration with building construction ensures optimal implementation and operation of the RE system and reduces the cost of the RE system. The model of providing the end users dedicated or centralised RE systems as a package with their residential flats/units is an effective way to promote RE integration in residential buildings. Similarly, making RE ready infrastructure an integral part of building design could significantly support its uptake. [Reference case studies: Magarapatta City, Pune and Royal Orange County, Pune]

Third party ownership model

- Third party ownership model (e.g. RESCO/OPEX model) is key to overcome two major existing barriers: high capital costs and uncertainty/doubt in RE technology performance. Such a model allows the customer to take the benefits of the RE system without investing upfront capital, thus significantly reducing risks over performance and O&M, which are the responsibility of the RESCO developer. [Reference case studies: Lunkad Sky Lounge Society, Pune, Indian Habitat Centre, New Delhi, Radisson Blu, Pune and Holy Family Hospital, New Delhi]
- However, there is a need for a supportive financial mechanisms such as availability of credit insurance mechanisms over an extended period/life of project, means for professional capital flow in the space, and partial equity finance to be in place to help RESCOs install more projects.

Technology alternatives

- Air source heat pump is an attractive solution for water heating applications in buildings having limited space and high hot water demand. It can also potentially overcome the issue of prioritising solar water heating or solar PV in a limited space. [Reference case study: Hotel Radisson Blu, Pune]
- Modular/plugin type biogas plants in high-rise buildings, hotels, restaurants, college hostels, industrial canteens, etc. could be easily installed to generate energy from wet waste. A wide range of modular type biogas plants are available in the market which have demonstrated the potential

to completely manage wet waste. [Reference case study: Thyssenkrupp Industries Ltd., Pune]

- Innovative implementation models, which encourage end-users to manage their energy demand can improve overall impact of the RE system (e.g. using solar PV in combination with solar water heater in high-rise buildings) towards reducing building energy consumption. [Reference case study: Royal Orange County, Pune]

Ensuring stakeholder benefit

- DISCOMs, municipal corporations, architects, RE system suppliers and installers, builders/developers, and end-users are the key stakeholders and should have measurable benefits and motivation to implement RE system in buildings. There is a need to ensure that all stakeholders get benefits and effectively communicate the benefits of implementing the RE system to consumers. Role of DISCOMs/utilities is critical for the success of renewable energy integration in buildings and their active involvement can expedite RE integration in buildings.

Policy measures and recommendations

- Net-metering arrangements help end-users to overcome the additional cost and maintenance related to electric battery storage and eliminates wastage of energy generated during non-operational days. Hence, net-metering improves the economics and viability of solar PV systems for customers. [Reference case studies: Aranya Bhawan, Jaipur and Lunkad Sky Lounge Society, Pune]
- There is an urgent need to bring in further uniformity and coherence between building codes like NBC, model building bylaws, ECBC, etc. to prevent confusion in guidelines suggested by each code and facilitate easier implementation of renewable energy related measures.
- Many benefits (direct or indirect) offered by on-site RE generation need to be communicated clearly to ULBs, e.g. improvement in livability index owing to reduced carbon emissions and improved air quality, ease in waste management, etc. which will prompt ULB's to ensure that various best practices related to RE are followed by buildings under their purview.
- Targets for RE integration in buildings must be set with reasonable flexibility. While an overall target at the national/state level can be set, different states/ULBs must be allowed to adopt a customized mix of RE technologies and their integration in different types of buildings, as per available local resources and requirements.
- Implementing incentive mechanisms for RE (if needed) (such as lower property tax, low interest loans, lower electricity tariff, etc.) through urban local bodies/DISCOMs and ensuring that these incentives work in coordination with the existing building codes will increase the willingness of building developers and users to install RE systems.
- Framing suitable policies to :
 - o Mandate optimal sizing of RE systems for water heating application in buildings like hotels, hospitals, etc. where hot water requirement is high

and round-the-year. Such demand could be met by SWH and air source heat pumps. Current policies do not address the issue of optimal sizing of SWH systems which can cater to a larger percentage of the hot water demand.

- o Encourage use of solar PV systems in high-rise building by ULBs to ensure that the PV system meets a certain part of electricity requirement by mandating reservation in roof top space for installation of solar PV.
 - o Incentivise the creation of RE uptake ready architecture/buildings.
 - o Promote integration of modular type/community level biogas systems in residential buildings and commercial buildings having high waste generation. This strongly aligns with the ULB goals and costs associated with waste collection, segregation, transport and management. Addressing issues of wet waste at site reduces the requirement of waste dumps and helps to avoid social conflict.
 - o Presently air source heat pumps are not officially recognized as a renewable energy technology in India. MNRE should urgently bring out a policy framework to address this gap. This would help in increasing confidence in this technology and help increase deployment.
- Ensure performance monitoring of RE integrated buildings. Making this performance data available in the public domain will help in building confidence in the technologies and its application in buildings.

Such measures are likely to ensure that the larger challenges preventing RE integration in buildings can be addressed and the process of RE integration is institutionalised.

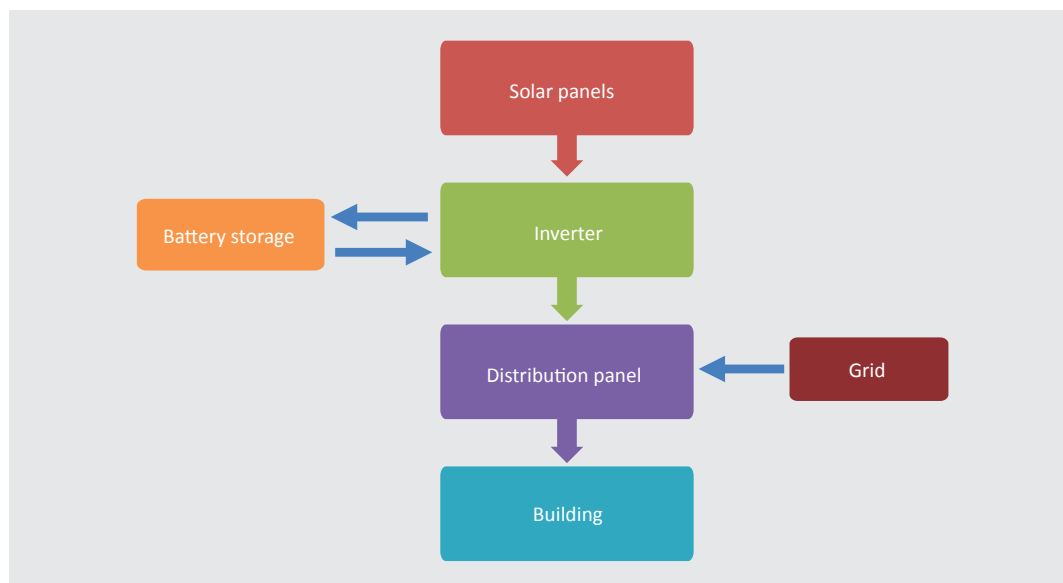
In the recent past, we have seen that utility and grid scale RE policies have allowed developers to take advantage of economies of scale leading to a significant reduction in utility scale tariffs. In the near term, conscious actions towards encouraging RE development through onsite generation can significantly contribute towards avoiding transmission losses, providing reliability in supply, and reducing expenses of pursuing grid supply.

Annexure 1 : Case Studies

A1.1 Residential building, Najafgarh, Delhi — Roof top solar PV

- A case study of roof top solar PV system installed on a low rise residential building was carried out. The building is a 3 storey building located near Indira service station, Dhansa road, Najafgarh, New Delhi.
- As a green initiative, owner has decided to install roof top solar PV system of 2 kW_p capacity during the construction time and then extend the capacity to 5 kW_p once the construction is completed. A solar PV system of 2 kW_p capacity with battery backup was commissioned in January 2016 by Solar Pulse Energy Pvt. Ltd.
- The schematic of solar PV system integration into the building is presented in Figure 16.

Figure 16 : Schematic of energy flow from solar PV system



It can be seen from the Figure 16 that the electricity produced by the solar PV system can be fed into the distribution panel or batteries by the inverter system in a priority manner.

The PLC of inverter works in such a way that the solar power first fed into the distribution panel of building, if any excess energy generated goes to charge the batteries for storing energy.

The inverter controls the power transport to building from sources, namely the solar PV panels, the battery storage system and the grid. If energy from solar panels and batteries is not available, then building loads are met by grid connection.

The technical details of the system are provided in Table 8.

Table 8: Solar PV system — Technical details

Type of system	Non-grid connected with battery backup
Type of panels	Silicon-based polycrystalline (uniform) panels
Panel manufacturer	Kosol Hiramrut Energies Pvt. Ltd.
Available rooftop area	92.93 m ²
Area covered by panels	16 m ²
Capacity of system	2 kW _p
Panel rating	250 W _p
Panel specifications	Peak Power Watts-PMAX (W _p): 250
	Power Output Tolerance-PMAX (%): ~ (+3%)
	Maximum Power Voltage-VMPP (V): 30.5
	Maximum Power Current-IMPP (A): 8.2
	Open Circuit Voltage-VOC (V): 37.7
	Short Circuit Current-ISC (A): 8.6
	Module Efficiency η (%): 14.6%
Panel dimensions	1 m x 2 m (area = 2 m ²)
No. of panels	8
Tilt angle	42 degrees
No of inverters	1
Inverter specifications	Make: VISPR-APPT
	Type: Charge controlled
	Nominal capacity - 5 kW

- It was estimated that the solar fraction for 2 kW_p solar PV system is ~20% (it will become ~50% if the system is expanded to 5 kW_p).
- One of the main advantage of installing the solar PV during the construction is that energy generated for the solar system can be used for lighting and water pumping. Hence, there is no need of temporary electricity connection during construction time.
- The cost of the 2 kW_p solar PV system with battery backup is ~2.24 lakhs, which is on the higher side. The simple payback period of the system is estimated at around 11–13 years. Hence, solar systems with battery backup systems are not economical.

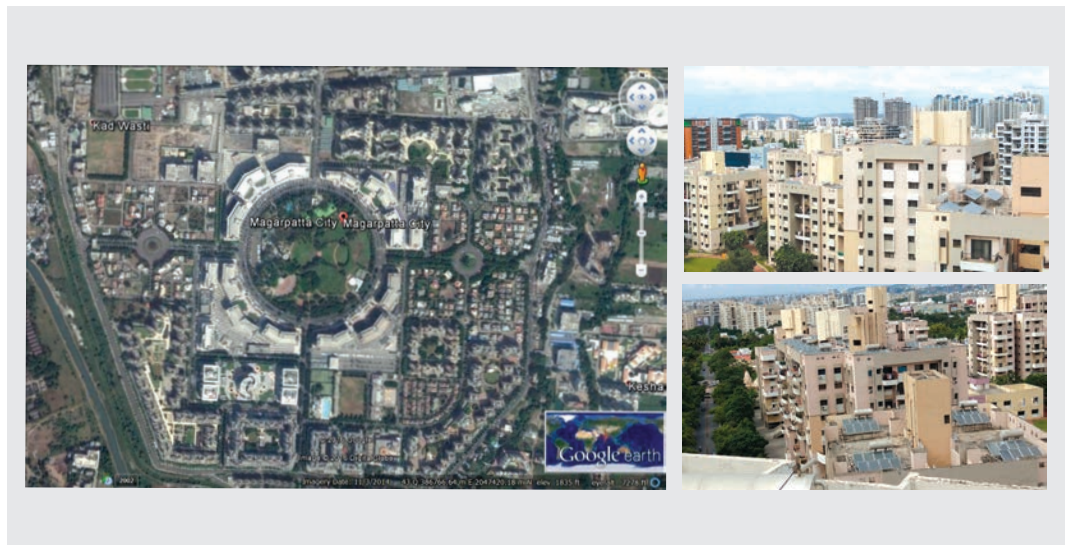
Conclusions :

- Since a solar PV system with battery backup systems is not economical, net-metering mechanism can make solar PV systems economical by eliminating/cutting down the battery costs.

A 1.2 Magarapatta City, Pune — Solar Water Heating (SWH) System

- Magarapatta, a township in Hadapsar area of Pune, India, is built over 600 acres of land, out of which 430 acres of land is used for building of residential and commercial buildings.
- As a green initiative, it was decided to provide solar water heating systems to each individual flat on their residential buildings. As a part of this initiation, a total of 8240 solar panels were installed in the entire township till date, having a solar collector area of 16,480 m². All the panels were integrated during the construction phase itself.

Figure 17 : Magarapatta city, site photos



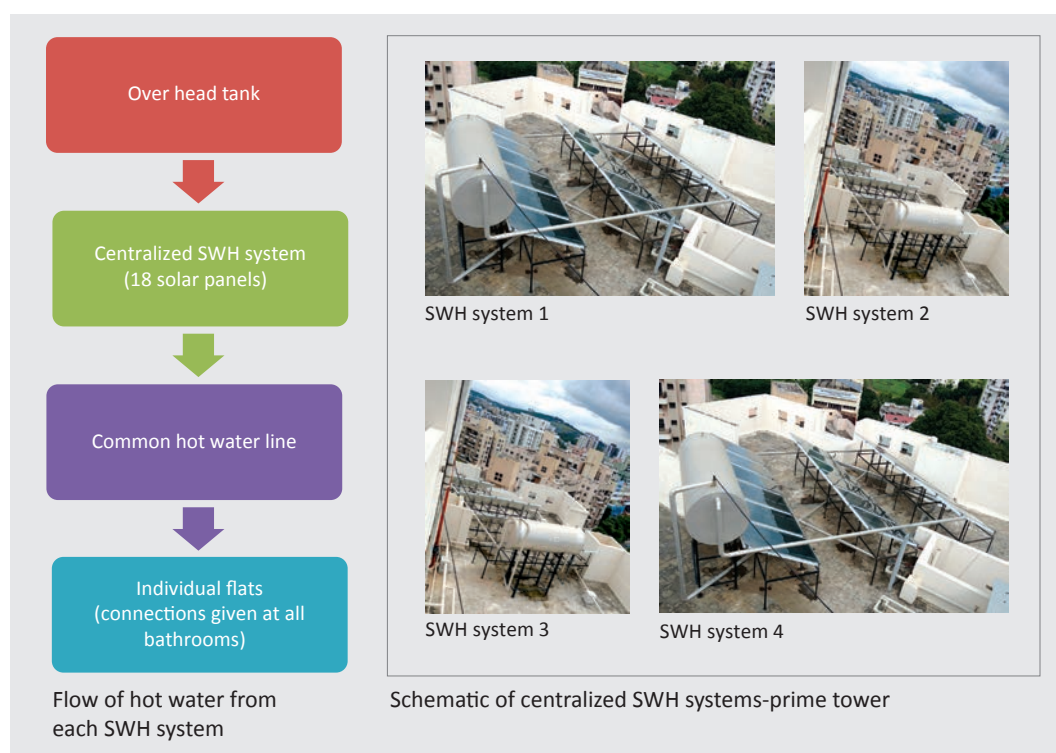
- As part of the present study, case study of SWH system, installed at one of the multi-stored residential buildings (Prime tower), was carried out.

Solar water heating system for Prime tower

- Prime tower is an 11 storey building consisting of 44 4 BHK flats, with four flats on each floor.
- Four centralised SWH systems were installed, each system is designed to supply hot water for 11 flats, one flat on each floor. SWH sizing for each flat is done as per its size.
- All the bathrooms of the flats were provided with solar hot water connections.
- Operation and maintenance of SWH systems is executed by Magarapatta City property management.

A representation of the solar water heating system is shown in the Figure 18.

Figure 18 : Schematic of centralised SWH system at Prime Tower



The technical details of the SWH system are given in the Table 9.

Table 9 : Solar water heating system — Technical details

Capacity of system	9000 LPD
Total collector area	144 m ²
Total no of solar panels installed	72
No of centralised SWH systems	4
Storage tanks	4 (2250 Leach)
	Insulation used: Rockwool
	Insulation thickness: 100 mm
Panel manufacturer	Bipin Engineers Pvt. Ltd.
Panel specifications	Collector type: Flat plate collector
	Absorber material: Copper
	Dimensions: 1 m x 2 m
	Maximum working pressure: 241 kPa
	Weight of empty panel: 44 kgs
Collector angle	34°

- Collector angle is optimised for the winter so that hot water is available at good temperature. The sun moves 15° south to latitude angle of Pune in the winter. Hence, collector should be tilted ~ 34° (18.5°+15°) towards south for the rays to fall perpendicular to the collector in the winter.
- The cost of solar water system is ~12.7 lakhs, which has a payback period of ~ 3 years.

Conclusions :

- It was understood from the residents that SWH systems meet hot water demand for most of the time in a year for small families. Flats with high population have one geyser as backup for cloudy/rainy days. Overall, solar fraction can be worked out as greater than 80%.
- Renewable energy integration during building construction and including RE cost in flat cost is a good business model.

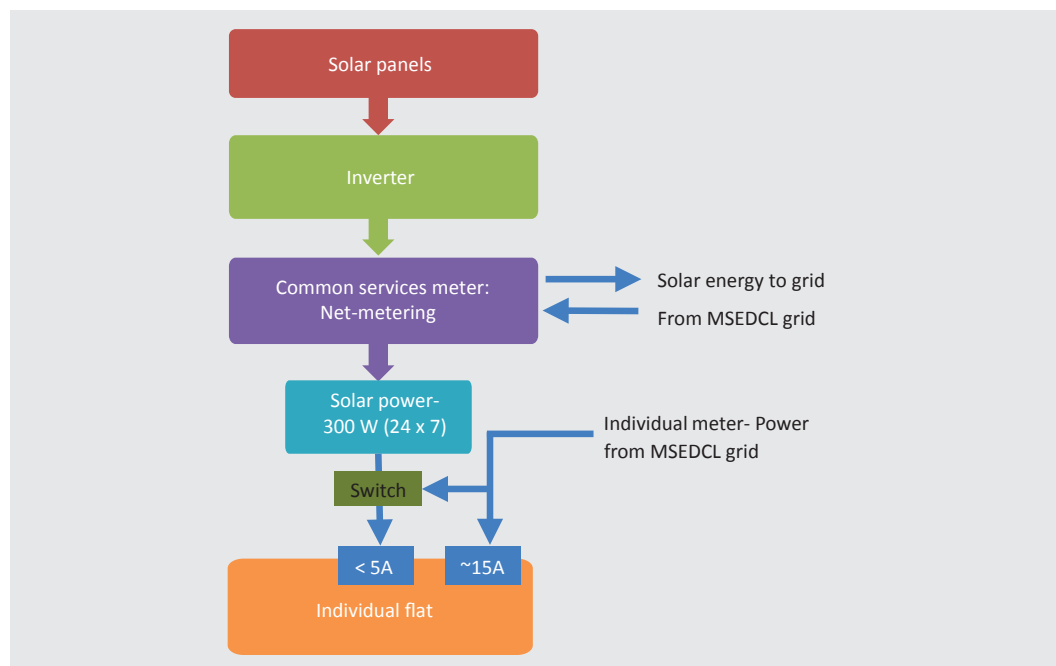
A 1.3 Royal Orange County, Pune — SWH + PV systems

- Orange County Group (OCG) has come up with a project named as Royal Orange County consisting of 8 residential apartments ranging from 9 to 12 floor buildings at Aundh Annexe, Pune. Each building is a combination of 2 and 3 BHK homes.
- Out of 8 buildings, 5 buildings were constructed, while the remaining 3 are under construction. As part of the green buildings initiative, the OCG incorporated solar PV and solar water heating systems design in the building design itself.
- Apart from solar systems, the OCG group developed in house wind turbines (in R&D stage) and biogas plants at the site to make the residential apartments carbon neutral buildings.
- As a part of this study, solar PV and SWH systems installed on Block E building are taken up for case studies.
- The Block E building consists of 44 flats, of which 22 are 2 BHK flats and 22 more are 3 BHK flats with ground floor parking. On the roof of this building, a solar PV system of 20 kW_p capacity and SWH system with collector area of 104 m² were commissioned in 2015. This apartment was occupied by residents in December 2015.

Solar roof top PV system

- The schematic of the solar PV system integration in the building is given in the Figure 19.
- It can be seen from Figure 19 that energy generated from solar PV goes to the common services meter where net-meter is installed.
- Separate connections from net-meter have been given to each flat which can provide green power of 300 W to each flat. The green power supply is given to the light loads which consume maximum of 5 Amp connections such as for lights, fans, TV, computers and kitchen exhaust etc. for 24 x 7 operation.

Figure 19: Schematic of Solar PV integration in the building



- Each flat has been installed with an Intelligent Automatic Changeover box to control the green power. If the light loads exceed 300W, a switch in the box changes the supply from net meter (i.e. solar power) to the grid.
- The power loads connected to the 15 Amp circuit such as the fridge and air conditioner directly take the supply from the grid. These loads are recorded in individual separate meters.

The technical details of the solar PV system are given in Table 10.

Table 10 : Technical details of solar PV system

Type of system	Grid connected rooftop solar PV system
Type of panels	Silicon-based polycrystalline panels
Panel manufacturer	Vikram Solar Private Limited
Area covered by panels	136 m ²
Capacity of system	20 kW _p
Panel rating	300 W _p
Panel specifications	Peak Power Watts- P_{MAX} (W _p): 300 Power Output Tolerance- P_{MAX} (%): 0 ~ +3 Maximum Power Voltage- V_{MPP} (V): 37.3 Maximum Power Current- I_{MPP} (A): 8.05 Open Circuit Voltage- V_{OC} (V): 45.1 Short Circuit Current- I_{SC} (A): 8.74 Module Efficiency _m (%): 15.5
Panel dimensions	1 m x 2 m (area = 2 m ²)
No. of panels	68
Tilt angle	18 degrees
No of inverters	1
Inverter specifications	Make: Sunny Tripower Type: Grid tied inverter Nominal capacities – 20 kVA

- The Capacity Utilisation Factor (CUF) is estimated as ~12.5%.
- The overall cost of 20 kW_p solar PV system is 14 lakhs which is include in the flat price.
- The simple payback period of the system is estimated to be around 5–6 years.
- It was estimated that solar fraction for solar PV is around 27%.

Solar Water Heating (SWH) system

- There are 44 panels of 125 LPD capacity installed on the roof of the building which occupies half of the roof area. Each SWH panel is connected to 2 bathrooms of each flat, combining 2 BHK and 3 BHK flats.
- In addition, 500 LPD SWH panels were installed for the 3rd Bathroom of 3BHK flats.
- The system was commissioned in 2015 by Akson's Solar Equipments Private Limited and Orange County.
- Apart from providing an SWH system, each flat is provided with one geyser to have hot water when the solar hot water is not available. Provisions have been given in each flat that additional geysers can be integrated with the SWH systems.

The solar water heating and PV systems installed on the roof of the building is shown in Figure 20.

Figure 20 : Site photos — Solar PV and SWH system installed on a roof top



The technical details of the SWH system are presented in the Table 11.

Table 11 : SWH system — Technical details

Collector type	Evacuated Tube collector
Collector area	104 m ²
No of panels	44 (125 LPD), 2 (500 LPD)
Panel area	125 LPD panel - 2 m ² (1 m x 2 m) 500 LPD panel – 8 m ² (2 m x 4 m)
No of tubes per collector	125 LPD – 12 500 LPD – 25
Tube Diameter	52 mm
Collector angle	25 degrees
Hot water end use points	Hot water connections are provided in all the bathrooms

- The overall cost of the water heating system is 7.8 lakhs.
- It was estimated that solar fraction for SWH is around ~ 70% – 80%.

Conclusions :

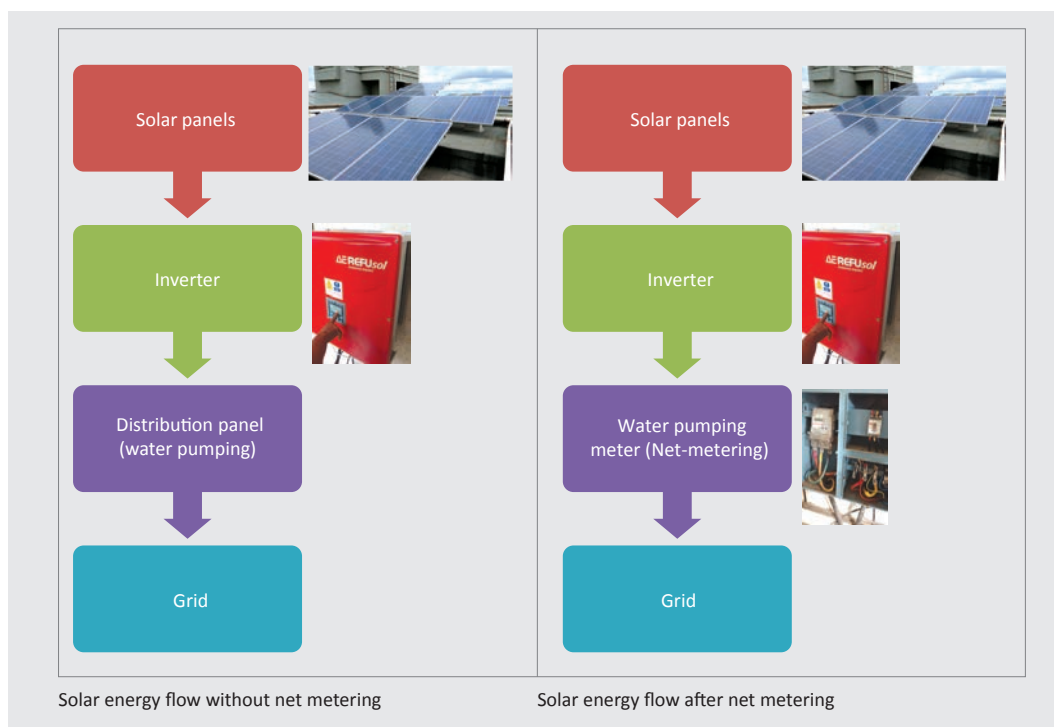
- It can be observed from this case study that a mix of SWH and solar PV systems can be installed on the roof of residential buildings as per the size of the flat and form of energy required to maximise the solar fraction.
- The model of dual electricity supply from grid and solar is a novel approach to design side manage (i.e., proper use of electrical appliances) and energy conservation (i.e., reduction in waste) at flat levels.
- The builder has moved from centralised SWH to individual SWH systems to get relief from maintenance of a centralised SWH system and other operational issues.
- It can be seen in this case that net-zero energy low-rise buildings are possible in moderate climates since solar fraction of electricity demand and water heating for an 11 storey residential apartment is around 27% and 75% respectively.

A 1.4 Lunkad Sky Lounge Society, Pune — Rooftop Solar PV

- Lunkad Sky Lounge is a society of 6 11 storey apartments located in Kalyani Nagar, Pune. As a green initiative, the management of the society installed 12 kW_p roof top solar PV system on one of the apartments.
- A solar PV system was commissioned in January 2016 under RESCO model by Fourth Partner Energy Private Limited. Under RESCO model, the project is owned and maintained by Fourth Partner Energy Private Limited for 20 years of time.
- The purpose of this project is to reduce the electricity costs for water pumping in the society. The society has separate distribution panel and meter for water pumping.

The schematic of solar PV system integration in the building is presented in Figure 21.

Figure 21: Schematic of energy flow from solar PV system



- It can be seen from Figure 21 (left-hand side diagram) that electricity produced by the solar PV system is fed into the distribution panel for water pumping before the net metering process.
- In this case, excess energy generated goes to the grid, and provides no benefit to the society. Hence, they applied for net-meter in place of a normal meter for water pumping. With net-metering, excess energy generated gets credited to the next month.
- The inverters are of grid tied type, installed to avoid the islanding effect, which means that when the power supply from the grid is cut off, solar power generation doesn't take place.

The technical details of the system are given in Table 12.

Table 12: Solar PV system — Technical details

Type of system	Grid connected
Type of panels	Silicon-based polycrystalline (uniform) panels
Panel manufacturer	Sri Savitr Solar Pvt. Ltd.
Available rooftop area	200 m ²
Area covered by panels	80 m ²
Capacity of system	12 kW _p
Panel rating	300 W _p
Panel specifications	Peak Power Watts-PMAX (W _p): 300
	Power Output Tolerance-PMAX (%): ~ +3%
	Maximum Power Voltage-VMPP (V): 36.37
	Maximum Power Current-IMPP (A): 8.25

	Open Circuit Voltage-VOC (V): 45.5
	Short Circuit Current-ISC (A): 8.85
	Module Efficiency η (%): 15.2%
Panel dimensions	1 m x 2 m (area = 2 m ²)
No. of panels	40
Tilt angle	18 degrees
No of inverters	1
Inverter specifications	Make: REFUSol
	Type: Grid tied inverter
	Nominal capacity - 10 kW

The performance details for 6 months (January 2016 to June 2016) are presented as shown in Table 13.

Table 13: Solar PV system — Performance details

Month	Energy consumption for water pumping (kWh)	Solar PV energy generation (kWh)	Solar fraction	CUF
Jan-16	2470	1194	48%	13%
Feb-16	2506	1185	47%	15%
Mar-16	2703	1066	39%	12%
Apr-16	2633	1511	57%	17%
May-16	2616	1496	57%	17%
Jun-16	3452	1187	34%	14%

- It can be seen from the table that the system has a solar fraction of 47%, i.e. solar PV system meets about 47% of the energy consumed for water pumping (this is achieved using roof area available on one of the buildings only). The capacity utilisation factor (CUF) of the system is 14.7%.
- The entire capital cost of the system is Rs. 9 lakhs which is invested by Fourth Partner Energy Private Limited under RESCO model. Under this model, the incremental power purchase agreement was signed for 20 years i.e., sky lounge society purchases solar power at Rs. 0.8 times multiplied by MSEB tariff per unit from the RESCO operator.
- At present the solar cost and MSEB costs are Rs. 9/unit and Rs. 11.3/unit. Therefore, Sky Lounge Society is saving Rs. 2.3/unit of solar energy produced without having made any investment. The saving number will increase with increase in MSEB tariff.
- It was calculated that simple payback period, considering present tariff structure, for this project is about 6.5 years.

Conclusions :

- Utilising power from solar PV systems with net-metering for common services like water pumping, lifts and common lighting is economically attractive where commercial tariff is applicable.
- Good potential to scale up and replicate in all buildings where commercial tariff is applicable for common services.
- One of the major problems faced by RESCO operator is significant delay in getting net metering approval as the whole process (from accepting applications to net meter installation) has not yet been streamlined in DISCOM offices.

A 1.5 India Habitat Center, New Delhi — Rooftop Solar PV

- India Habitat Center (IHC) is a multipurpose building for social and commercial use, with offices of banks, NGOs and companies like TERI, HUDCO, IREDA, ICERIR, CII, etc.
- As a green initiative, the IHC decided to opt for a roof top solar PV system on their campus buildings. It was decided, after site evaluation, to install a solar PV system of 250 kW_p capacity on 5 buildings on campus as shown in Figure 22.
- This project was commissioned in March 2015 under RESCO mode. The project is owned by JBM Solar Pvt. Ltd., who have hired SunSource Energy Pvt. Ltd. to install, operate and manage the system. First Green Consultation Pvt. Ltd., the consultant for this project, was responsible for the entire planning and implementation.

Figure 22: Google earth image of solar PV system installed at IHC



System description :

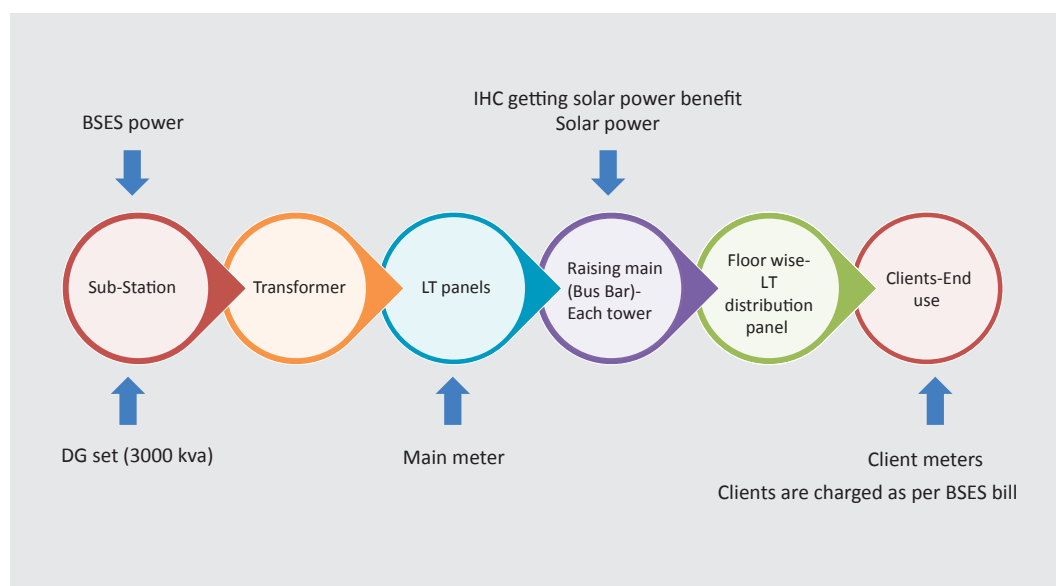
- The solar system of 250 kW_p capacity was installed on 5 buildings as 5 individual systems with different capacities as shown in Table 14.

Table 14: Installed solar PV system — Building wise

Building name	Installed capacity (kW _p)
Building 4A	17.67
Building 5A	44.64
Building 6A	65.1
Building 6C	50.22
Building 7A	72.54
Total	250

- The schematic of solar PV system integration into the buildings is presented in Figure 23. It can be seen from Figure 23 that electricity produced by each individual solar PV system is fed into the rising main of that building, and gets mixed up with the BSES electricity.
- The solar power produced is supplied at a slightly higher voltage as compared to the BSES power to ensure that it gets consumed first.

Figure 23 : Schematic diagram of solar PV system integrated into the buildings at IHC



- The inverters, are of grid tied type, installed to avoid the islanding effect, which means that when the power supply from the grid is cut off, solar power generation doesn't take place.

Technical details

The technical details of the system are provided in Table 15.

Table 15: Solar PV system — Technical details

Type of system	Non grid connected rooftop solar PV system
Type of panels	Silicon-based polycrystalline (uniform) panels
Panel manufacturer	Trina solar
Available rooftop area	4060 m ²
Available shadow free rooftop area	2526 m ²
Area covered by panels	1618 m ²
Capacity of system	250 kW _p
Panel rating	310 Wp
Panel specifications	Peak Power Watts-P _{MAX} (Wp): 310 Power Output Tolerance-P _{MAX} (%): 0 ~ +3 Maximum Power Voltage-V _{MPP} (V): 37.0 Maximum Power Current-I _{MPP} (A): 8.38 Open Circuit Voltage-V _{OC} (V): 45.5 Short Circuit Current-I _{SC} (A): 8.85 Module Efficiency η_m (%): 16.0
Panel dimensions	1 m x 2 m (area = 2 m ²)
No. of panels	809
Tilt angle	10 degrees
No of inverters	11
Inverter specifications	Make: Delta Type: Grid tied inverter Nominal capacities – 20 kVA – 25 kVA

- All the panels have been tilted at an angle of 10 degrees, not the latitude angle of the location, even though this tilt causes a 5% loss in solar power as compared to the conventional tilt. There are multiple reasons behind this. Firstly, the client did not want the panels to be visible. Secondly, at a higher angle, because of mutual shading of panels, the capacity of the system will be reduced. As the floor of the roof can't be drilled, the ballasted roof mounting system was selected to install the PV panels.

Performance details

- The total amount of energy generated by the solar PV system per month, starting from April 2015 to March 2016, is tabulated in Table 16.

Table 16: Solar PV system — Performance details

Month	Total building energy consumption (kWh)	Solar PV energy generation (kWh)	Capacity Utilization Factor (CUF) ³⁷	Performance Ratio (PR) ³⁸
April (2015)	1,011,000	32,552	18.1%	66.5%
May (2015)	1,175,400	34,342	18.5%	66.7%
June (2015)	1,200,960	27,181	15.1%	57.7%
July (2015)	1,282,200	27,416	14.7%	65.5%
August (2015)	1,260,120	28,023	15.1%	72.6%

37. CUF = Actual solar energy generation per year (kWh)/Installed capacity (kW_p) * 24 * 365

38. PR = Actual solar energy generation per year (kWh)/theoretical energy generation (kWh)

September (2015)	1,187,880	33,319	18.5%	84.8%
October (2015)	1,036,680	27,805	14.9%	71.7%
November (2015)	779,280	16,576	9.2%	51.1%
December (2015)	735,240	16,903	9.1%	59.8%
January (2016)	750,120	16,080	8.6%	52.7%
February (2016)	636,600	23,792	13.7%	70.2%
March (2016)	816,120	30,939	16.6%	66.5%
Total	11,871,600	314,928	14.4%	65.9%

- It can be seen from the table that the system has a solar fraction of 2.7%, i.e. solar PV system meets about 2.7% of the building's energy needs. The Capacity Utilisation Factor (CUF) and Performance Ratio (PR) of the system are 14.4% and 65.9% respectively.

Financial details

The following Table 17 shows the component wise break-up of the capital cost.

Table 17: Solar PV system — Cost details

Component	Cost (INR/Wp)
Panels	50
Invertor	6
Battery	Not installed
Charge controller	Not installed
Structure, mountings (tracking)	5.5
Installation (labour)	5
Others (monitoring system, BOS etc.)	20
Total	86.5

- The entire capital cost of the system was Rs. 2.66 crores, out of which an upfront grant of Rs. 50 lakhs given by M/s ILFS and M/s IIFCL who both gave Rs. 25 lakhs each. The entire investment was made by JBM Solar Pvt. Ltd.
- The overall maintenance of the system includes cleaning of the entire system, site visits, data collection and reporting, and averages to about Rs.100/kW_p i.e., Rs. 25,000 per month.
- The power generated through solar panels is purchased at Rs. 4.99 per unit by IHC whereas the BSES cost is Rs. 8.4/unit. Therefore, IHC is saving 3.4/unit of solar produced energy without having made any investment, other than the grant given to JBM Solar.
- It was calculated that the payback period for this project is about 13 years.

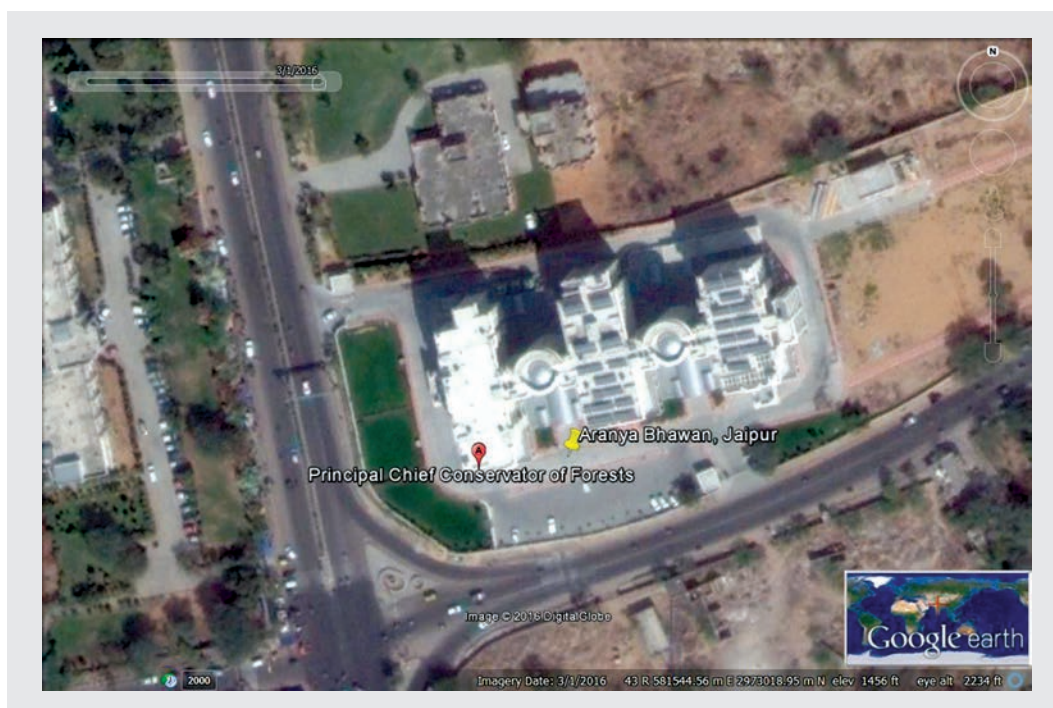
Conclusions:

- RESCO model seems to be economically beneficial for commercial buildings but the economics of RESCO model projects needs to be understood and further investigated from RESCO company's perspective.

A 1.6 Aranya Bhawan, Jaipur — Rooftop Solar PV

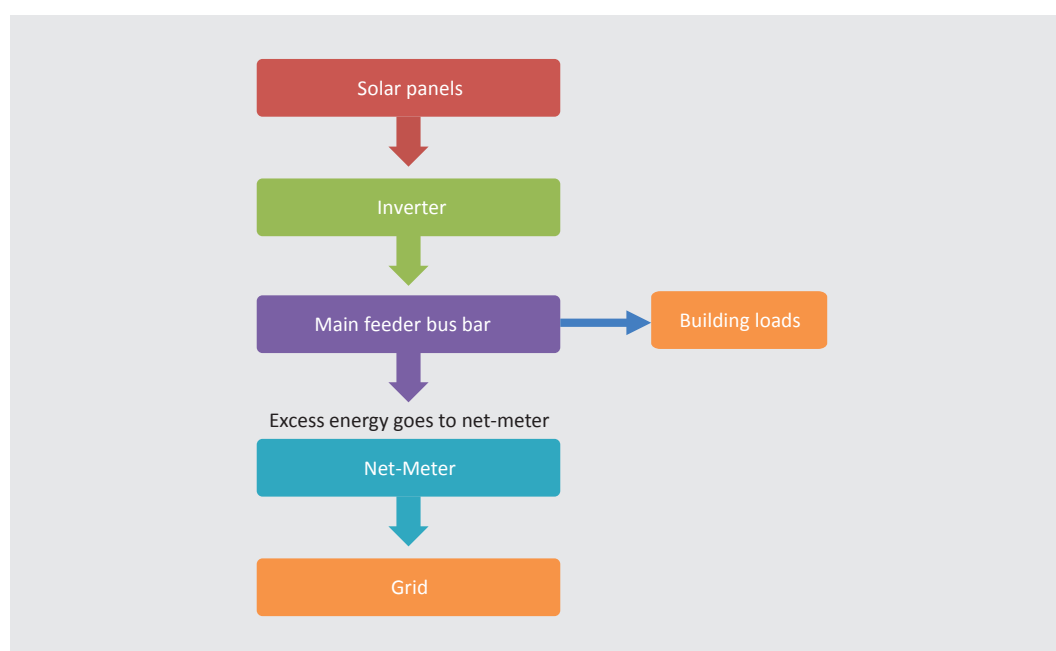
- Aranya Bhawan is the new office building for the Rajasthan Forest Department. It has been designed as a G+4 structure with one basement for parking and is envisaged for 250 users. The total built-up area is 14,000 square meters. There are three distinct blocks, which are connected by corridors and two staircase blocks.
- The building was inaugurated in March 2015 and is being occupied since April 2015.
- As a part of the green initiative, a solar PV system of 26 kW_p capacity was installed in October 2015 and expended to 45 kW_p in January 2016.

Figure 24: Google earth image of solar PV system installed at Aranya Bhawan



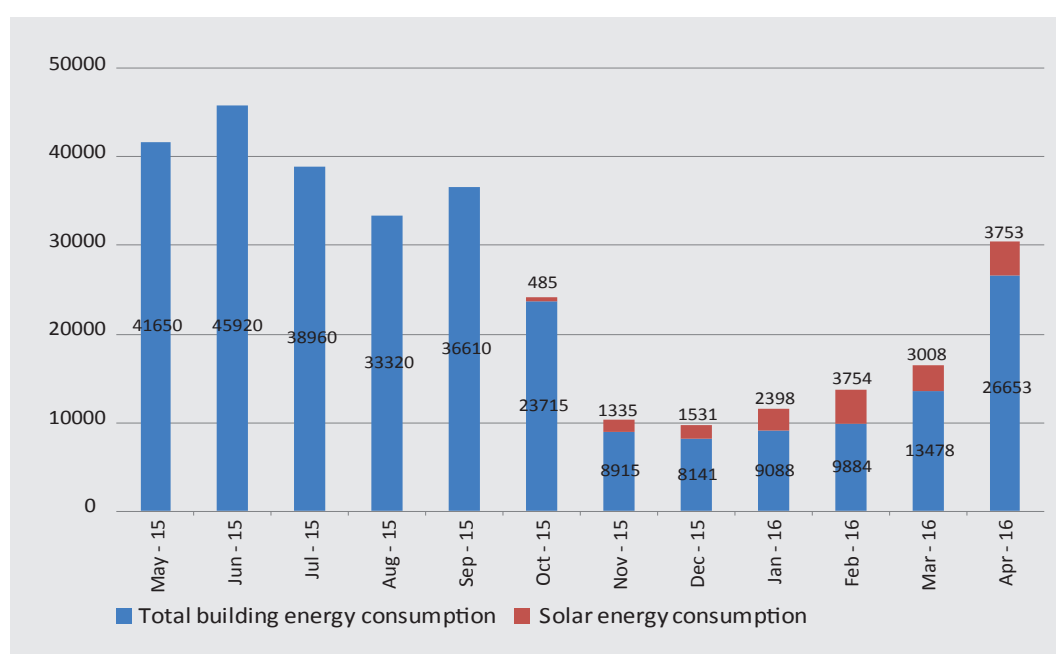
- The solar system of 45 kW_p capacity was installed on the roof of the buildings as shown in Figure 24.
- The schematic of solar PV system integration into the buildings is presented in Figure 25. It can be seen from Figure 25 that electricity produced by each individual solar PV system is fed into the bus bar of the main feeder in the building, and gets mixed up with the grid electricity.
- The solar power produced is supplied at a slightly higher voltage as compared to the grid power to ensure that it gets consumed first.

Figure 25 : Schematic diagram of solar PV system integrated into the buildings at Aranya Bhawan



- Net-meter was installed in the month of April 2016 to ensure that energy from PV panels is generated during non-working days (weekends, holidays) when office building is not occupied.
- The inverters, are of grid tied type, installed to avoid the islanding effect, i.e. when the power supply from the grid is cut off.
- The total amount of energy generated by the solar PV system per month against building energy consumption, starting from October 2015 to April 2016, is shown in Figure 26.

Figure 26: Comparison of building energy consumption and solar energy generation



- It was estimated that annual solar energy generation is 60,000 units which meets about 20% i.e., solar fraction of the buildings energy needs.
- The energy bills (JVVNL electricity bills) do not reveal energy exported (to the grid) by the solar PV plant.

Conclusions :

- Net-metering ensures 100% capacity utilisation of the solar PV system throughout the year. Power generation from the system is possible even on non-working days of the buildings like weekends and holidays.
- This model can be replicated to public office buildings (low-rise, large roof area availability).

A 1.7 NETRA, Noida — Solar Cooling + Solar PV systems

- NETRA (NTPC Energy Technology Research Alliance) was set up in 2009. The company is fully aligned to the needs of adapting to emerging technologies and upgrading the technologies through research and development. As a part of this vision, initiatives were taken to install a solar thermal cooling system and a solar PV system at their research centre as shown in the Figure 27. Solar thermal cooling system was commissioned in 2012 and solar PV system in November 2015.

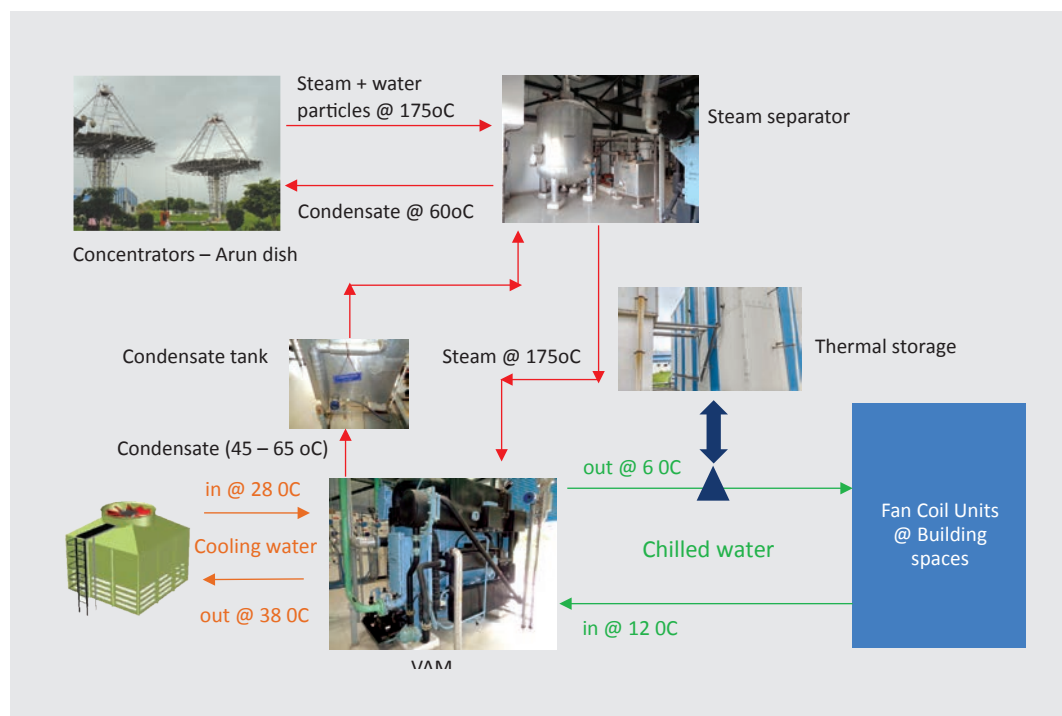
Figure 27: Solar cooling system and roof top PV system installed at NETRA building office



Solar thermal cooling :

- 2 ARUN dish type solar concentrators were installed at the open space available beside the building (see Figure 27) to produce an air-conditioning effect of 40TR through a vapour absorption system.
- The schematic of the solar thermal cooling system is given in Figure 28. It can be seen from Figure 28 that solar concentrators produce wet steam at 8 bar and 175 °C, which goes into the steam separator tank where the dry and wet steam is separated.
- The dry steam then goes into the Vapour Absorption Machine (VAM), and wet steam remains in the steam separator tank. The dry steam (source of heat) goes as input to the VAM machine and changes its phase into liquid and then goes to the condensate tank.
- The condensate from the condensate tank goes to the steam separator tank which in turn goes to solar concentrators where solar heat is absorbed and then supplied again to the VAM system. The process continues till adequate solar energy falls on the concentrators.
- Chilled water is produced from the VAM machine at 6 °C, which is sent to the individual fan coil units (FCUs) retrofitted in the top floor of the building.
- Thermal storage system is also installed to store the chilled water generated on weekends and holiday days to offset the cooling requirement during the working days.

Figure 28: Schematic of solar thermal cooling system operation



The technical details of the solar thermal cooling system are given in Table 18.

Table 18: Solar thermal cooling system — Technical details

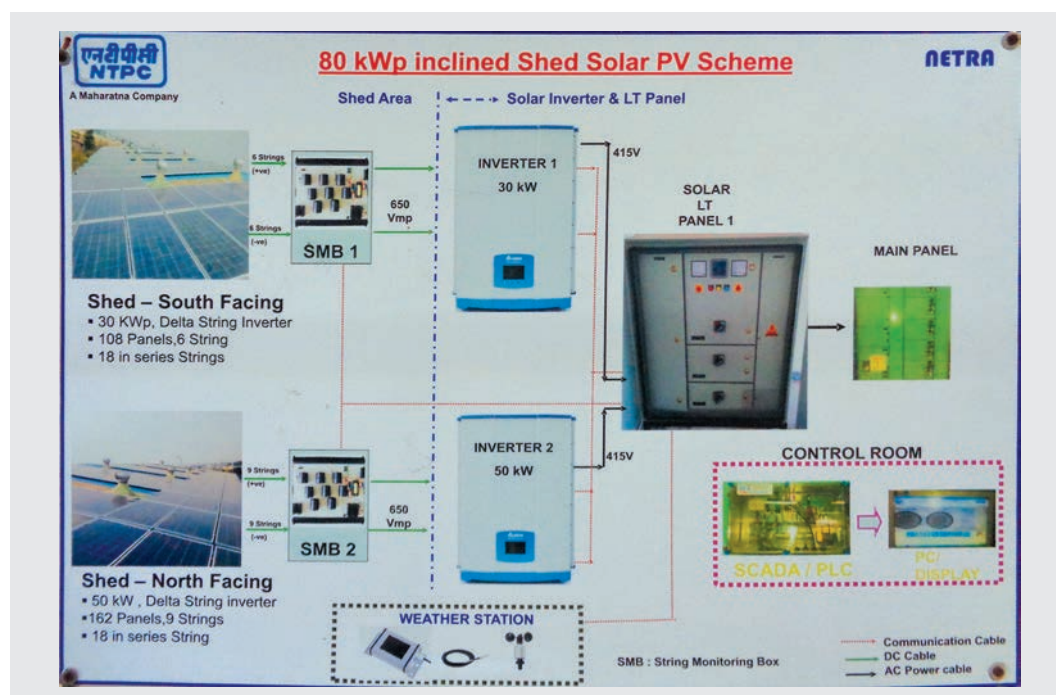
Thermal properties	Thermal rating: 70 - 90 kW
	Operating temperature/pressure: 185°C/11.5 bar
	Working fluid: Steam & Water
	Operating wind speed: Up to 43 kmph
	Survival wind speed: Up to 162 kmph
No of ARUN dish	2
Optical parameters - single dish	Aperture area: 169 m ²
	Reflector area: 141 m ²
	Optical efficiency: 0.65
	Solidity factor: 0.84
	Intercept factor: 0.90
	Reflectivity: 0.955
	Specular reflectivity: 0.93
Geometry - single dish	Diameter: 14 m
	Aerial space: 18 x 18 x 16 m
	Foot-print: 3 x 3 m
VAM specs	Type: Li-Br based VAM
	Capacity: 50 TR
	COP: 1.3
Thermal storage capacity	500 m ³

- The solar thermal cooling system has been operational from 2012 till date, but thermal storage is not operational.
- The overall cost of solar thermal cooling system is 2.5 crores (40TR air conditioning).

Solar roof top PV system

- Solar panels were mounted on the gable roof of the in-house workshop. The roof of the workshop has two sloped surfaces at different angles. Accordingly, two solar PV systems of 50 kW and 30 kW were installed on the north-east and south-west facing roofs respectively at different angles.
- Being installed at different tilt angles, both the systems will have different operational efficiencies.

Figure 29 : Schematic of solar roof top PV system



The technical details of solar PV system are given Table 19.

Table 19: Solar PV system — Technical details

Type of system	Grid connected rooftop solar PV system
Type of panels	Silicon-based polycrystalline (uniform) panels
Panel manufacturer	Waaree Energies Ltd
Available rooftop area	842 m ²
Area covered by panels	540 m ²
Capacity of system	North - East facing: 50 kW South - West facing: 30 kW Total: 80 kWp
Panel rating	300 Wp
Panel specifications	Peak Power Watts-PMAX (Wp): 300
	Power Tolerance: 0 / +5 W
	Maximum Power Voltage-VMPP (V): 36.5
	Maximum Power Current-IMPP (A): 8.22
	Open Circuit Voltage-VOC (V): 45.0
	Short Circuit Current-ISC (A): 8.89
	Module Efficiency _m (%): 15.46
Panel dimensions	1 m x 2 m (area = 2 m ²)
No. of panels	270
No of inverters	2
Inverter specifications	Make: Delta Type: Grid tied inverter Nominal capacities – 50 kVA & 30 kVA

- The overall cost of 80 kW_p solar PV system is 40.8 lakhs which excludes 30% MNRE subsidy.
- The simple payback period of the system is estimated around 5 – 6 years.
- The Capacity Utilisation Factor (CUF) is estimated as ~12.5%.

Conclusions :

- Capital cost for solar cooling system is very high as compared to conventional system.
- Proper integration of solar cooling system with conventional HVACs is critical for its maximum utilisation.

A 1.8 Holy Family Hospital, New Delhi — Solar Water Heating System

- Holy Family Hospital (HFH), New Delhi is a 303 bedded multi-specialty hospital run by the New Delhi Holy Family Hospital Society and managed by the Delhi Catholic Archdiocese.
- As a green initiative, HFH society has decided to use solar systems for their own applications. As a part of this initiative, solar water heating (SWH) system and solar PV system were installed on the free roof of hospital buildings in 2009 and 2015 respectively. Both the systems were installed under RESCO mode.
- The SWH system installation (marked in red, remaining panels are solar PV panels) on the building roof is shown Figure 30. In this paper, solar water heating system of 200 m² collector area was taken up for the case study (as the solar PV RESCO operator was not willing to share the details).

Figure 30: Google earth image of SWH installed at HFH

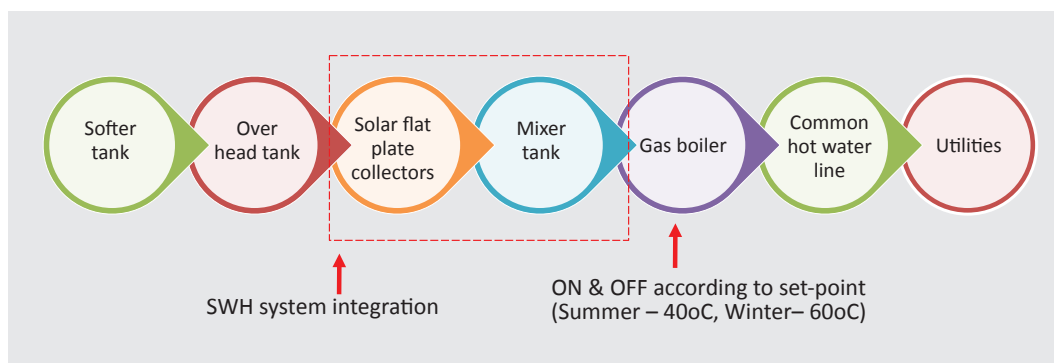


- The SWH system was commissioned in February 2009, under RESCO mode, by Trans Solar Technologies, Tamil Nadu.
- The total hot water demand at HFH is 20 kL/day and 23 kL/day in summer and winter respectively.
- As per the purchase agreement, the project was owned by Trans Solar Technologies since installation for 7 years and transferred to HFH in 2015.

System description :

- The flow of water in the hot water generation system is shown in Figure 31. The solar flat plate collectors were installed in the existing water heating system before the gas boiler with a mixer tank.
- The SWH system was integrated in series with gas boiler so that the entire water demand goes first through solar panels and then to the gas boiler.

Figure 31: Schematic of hot water system installed at HFH



Technical details :

The technical details of the SWH system are presented in Table 20.

Table 20: SWH system — Technical details

Collector type	Flat plate collector
Collector area	200 m ²
No of panels	100
Panel area	2 m ² (1 m x 2 m)
Tube material	Copper
Type of absorber	Copper fins with carbon coating
Collector angle	45
No of mixer tanks	4
Capacity of mixer tanks	2500 L each
Primary backup	3 gas boilers
Gas boiler capacity	1500 L each
Secondary back up	Electric heaters
End use of hot water	Kitchen, washing of plates and dishes, laundry, OT, ICU, etc.

- As shown in Figure 31, the water from the overhead tank flows to the solar water panels, is heated up and then goes to the mixer tank.
- Hot water from the mixer tank goes to the boiler where if the water temperature is below the set point temperature, gas is burnt in the boiler to raise the temperature of water to set point temperature and then supplied to the utilities.
- The set point of hot water supply was varied between 40 C to 60 C according to the end use required in different seasons.

Other details :

- The gas consumption for hot water generation before SWH installation was ~ 4500 m³ per month, which cost around Rs. 85,000 per month.
- After the SWH installation, the gas consumption on an average has come down to 1000 m³ per month. During the 7 years of RESCO operation, HFH agreed to pay an amount of Rs. 51,000 as gas bill charges per month. The savings was worked out as Rs. 34,000 per month.
- Solar fraction was worked out to be 78% of total demand.
- HFH is enjoying the whole benefit of reduction in gas bill after the project has been handed over to it in 2015.

Conclusions :

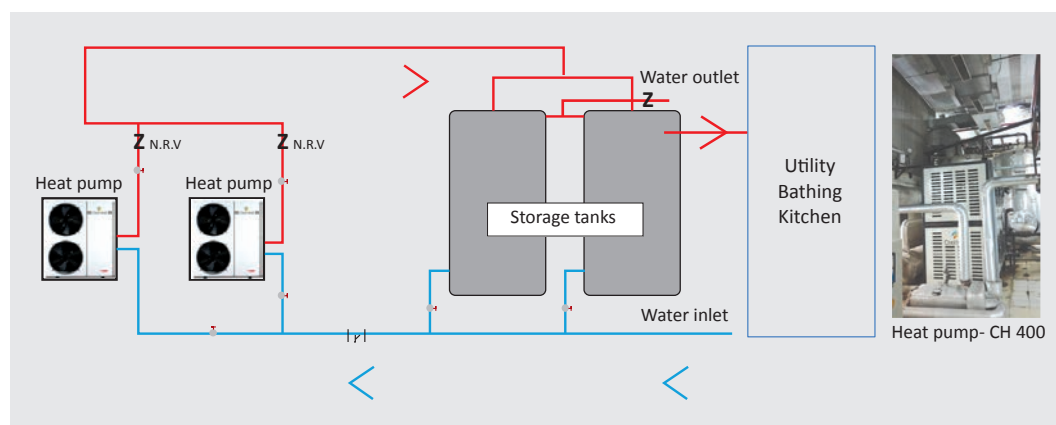
- RESCO model of SWH for commercial purpose seems to be economically beneficial for both client and the RESCO operator.
- In commercial buildings like hospitals, institutions and hotels where ample roof area is available, this space could potentially be used to meet the entire hot water requirement of the buildings.

A 1.9 Radisson Blu, Pune — Air Heat Pump (AHP) system

- A case study on air heat pump was carried out at 5-star Radisson Blu hotel. The hotel is located at Tulja Bhawani Nagar, Kharadi, Pune.
- The hotel is a 5 storey building consisting of 220 rooms. The hot water demand for bathing and kitchen use is ~ 40,000 L per day.
- The hotel management decided to install air heat pump in place of diesel boiler to cut down the diesel costs for water heating.
- Air heat pump system of 40 TR capacity was commissioned in April 2015 by Brio Energy Pvt. Ltd., Pune under RESCO mode.

A representation of the air heat pump system is shown in the Figure 32.

Figure 32: Schematic of air heat pump working



- As shown in the above figure there are 2 heat pumps units, consisting of two compressors each, installed in the basement of the hotel.
- An air heat pump is a microprocessor-controlled heating unit which transfers heat from outside (ambient) air to water. Under the principles of vapour compression refrigeration, it provides hot water without additional energy.
- The technical details of the air heat pump system are given in Table 21.

Table 21: Air heat pump — Technical details

Type of system	Air heat pump
Capacity of system	139.2 kW (Heating)
Heat pump manufacturer	Brio Energy Pvt. Ltd
No. of heat pump units	2 (Identical) – 4 compressors
Single heat pump specifications	Model - CH400
	Compressor rating - 10 kW
	COP rated - 3.48
	Refrigerant - R407C
	Hot water generation capacity - 1000 l/hr
	Hot water designed output temperature - 55 Deg.

- Hot water is generated at around 55° C from the air heat pump, and is used for bathing and cleaning utensils in the kitchen. But the hot water for laundry is generated from diesel boiler as the water temperature required for this application is very high.
- The project was implemented by Brio Energy Pvt. Ltd. under the RESCO mode for 15 months of the time. The project cost after getting 80% accelerated depreciation benefit on first year is 19 lakhs.
- As per the agreement made under the RESCO mode, Radisson Blu paid around 1.3 lakhs per month for 15 months of time. Hence, total project cost was recovered by Brio Energy in 15 months of time.
- Operation and maintenance of the air heat pump system was under the scope of Brio Energy Pvt. Ltd. for this time.
- The diesel consumption of boiler before installing the air heat pump was ~ 200 L per day. It has come down to ~ 52 L per day after installing the air heat pump. Hence, Radisson Blue saved around 148 L per day.

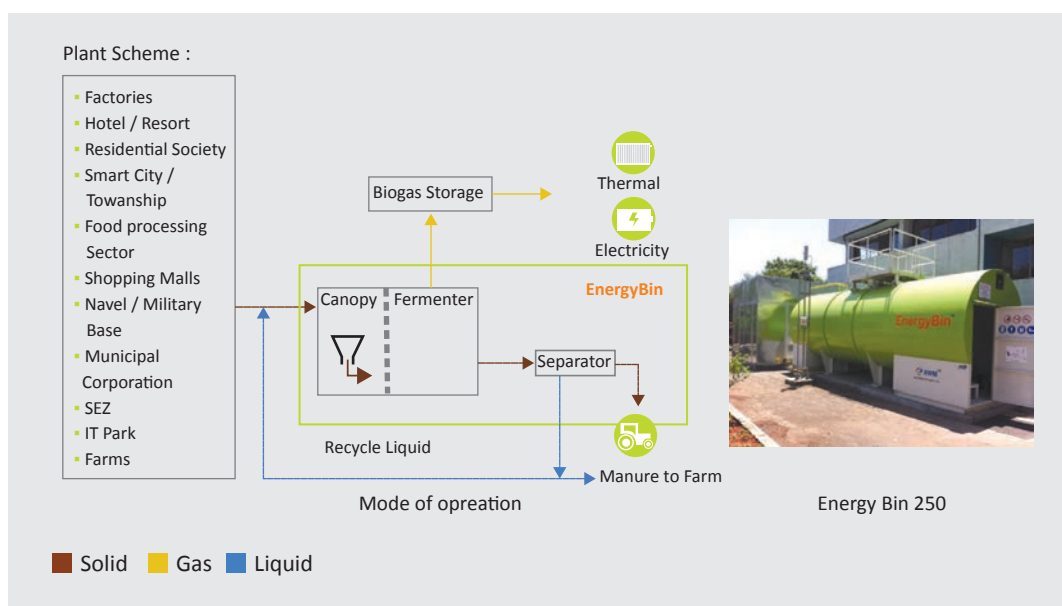
Conclusions :

- It can be understood that air heat pump can become an alternative technology for hot water generation below 85° C in place of conventional heating systems like resistive type and fossil fuel systems.
- The promising building segments for air heat pumps are hotels, restaurants, hospitals, etc. where limited roof area is available.
- Solar water heating coupled with air heat pump hybrid systems for hot water generation could become an attractive option for commercial applications where substantial roof area is available.

A 1.10 Thyssenkrupp Industries Ltd, Pune — Biogas Plant

- A case study of biogas system installed on an industrial canteen building was carried out. The building is located near Pimpri, Pune.
- Since the Thyssenkrupp Industries Ltd. is located in the middle of the city, waste disposal has become a difficult task and involved higher costs in disposal. Therefore, the management has taken a decision to install a biogas plant near their canteen to reduce their costs on waste disposal and LPG costs for cooking.
- The biogas plant, called EnergyBin 250, was installed by Xeon Waste Managers LLP in 2014. The schematic of the biogas plant operation is presented in Figure 33.

Figure 33: Schematic of biogas plant operation and Energy Bin 250



- The raw material is processed to remove the metallic or other dry waste pieces from the feedstock and then wet waste is brought to the biogas plant.
- The filtered wet waste is then pumped into the crusher for faster and efficient digestion. The feedstock is fed into the digester and X-Additives like enzymes and nutrients are introduced to further boost the digestion process, improve effectiveness of the conversion, and enhance the quality of biogas. This initiates an anaerobic reaction that converts the bio-degradable solid and liquid waste into biogas, liquid manure and solid manure.

- The entire progress can be monitored on the control panel set up in the chamber. All the parameters that affect the efficiency of conversion like temperature, pH levels, microbial count, mixing, etc. can be controlled through a single dashboard.
- The biogas that is generated will be stored on top of the plant and then sent to the kitchen for cooking on demand.
- EnergyBin is a multi-stage digestion system that converts bio-degradable waste into bio energy. This includes conversion of solid/wet bio-degradable wastes like food, industrial, animal and human waste into clean biogas, solid manure and liquid manure that can be used in agriculture, thermal and electrical applications. The entire set up is easy to install and operate. Its portable nature makes it a plug-n-play plant.

The technical details of the system are given in Table 22.

Table 22: EnergyBin 250 — Technical details

Type of system	Plug in and portable biogas plant
Model	EnergyBin 250
Waste processing capacity	250 kg
Digester volume	22 m ³
Digester dimensions	9 X 2.5 X 3 m
Biogas output	30-32 m ³ /day
LPG Equivalent	15 kg
Manure output	300 L

- The overall cost of the EnergyBin 250 is ~ 9.7 lakhs after having got 80% acceleration depreciation in the first year.
- It was estimated that the electrical energy required to operate the biogas plant is around 6 kWh/day.
- The annual net revenue generated is around 7.1 lakhs, out of which around 3 lakhs come from LPG savings, 3 lakhs from avoiding waste disposal costs and 1 lakh from sell of manure.
- The simple payback period of the system is estimated around 1.2 years.

Conclusions :

- Portable type biogas plant is a good model for schools, hotels, hostels and residential buildings for generating power or using biogas for cooking purpose.

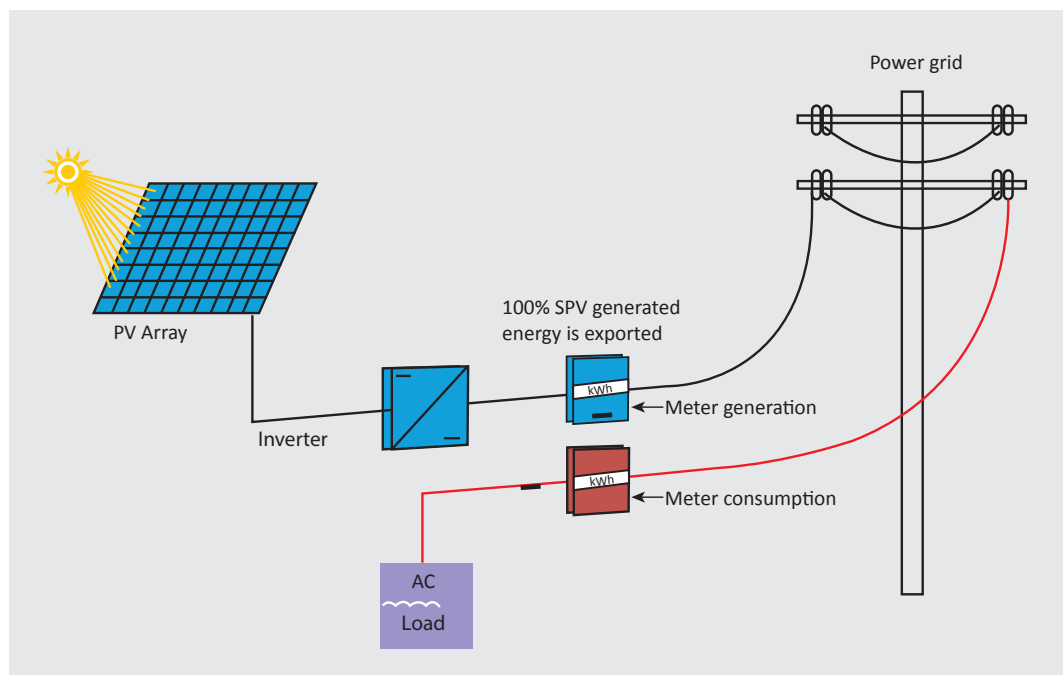
Annexure 2 : RE technologies integration models for buildings

A 2.1 Solar PV integration models in buildings

The output of solar PV system can be integrated in buildings in four types of configurations as per system capacity, building loads and operations. They are:

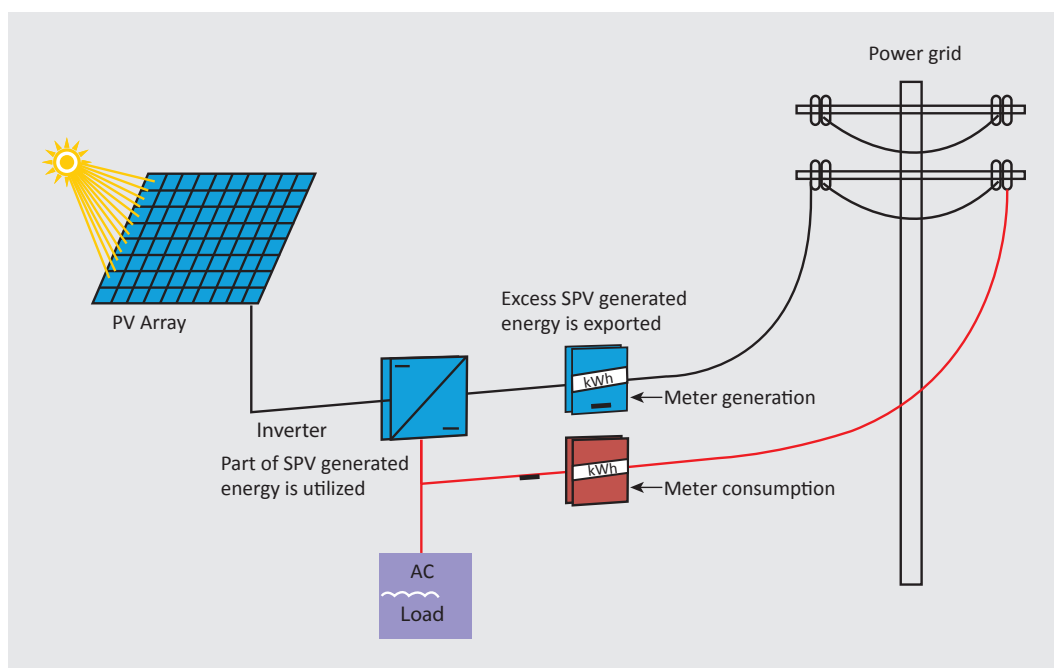
1. **Grid-connected with net metering and 100% export:** In this system, the building has two meters. One meter measures the electricity generated from the solar PV system, which is fed to the grid. The other meter measures the electricity consumed by the building, which is taken from the grid. The building energy consumption in a billing cycle is calculated as difference between the energy consumed from the grid and the energy generated from solar. The electricity bill is calculated based on the solar PV generated electricity and its tariff, and the electricity consumed from the grid and its tariff. The schematic of this configuration is shown in Figure 34.

Figure 34 : SPV schematic for grid-connected with net-metering and 100% export



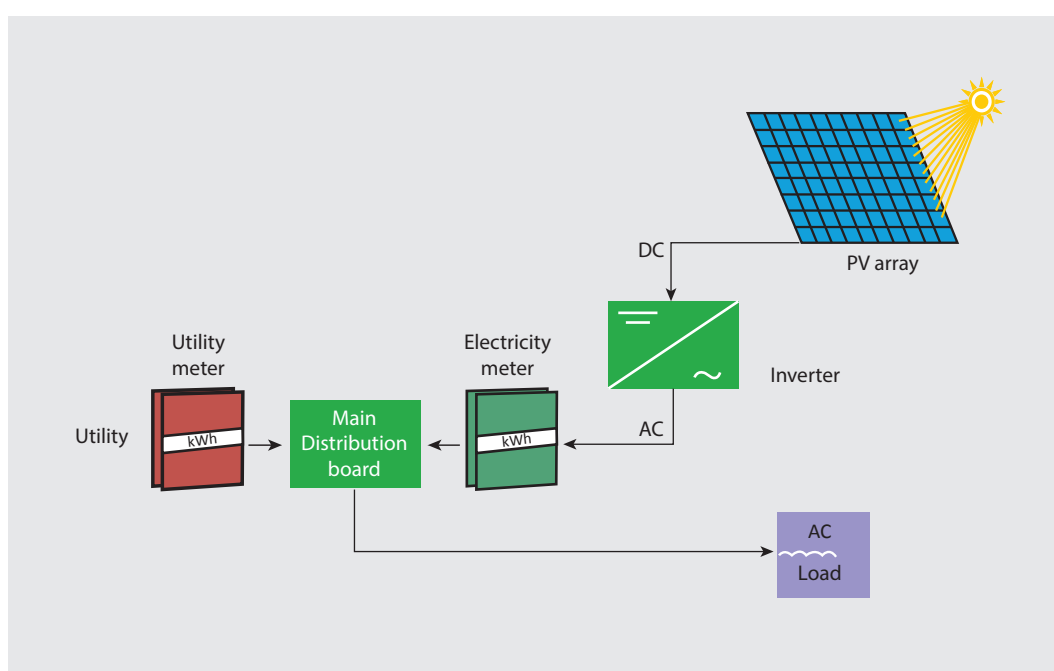
2. **Grid-connected with net metering and excess energy export:** This configuration is exactly the same as the previous one, the only difference being that a part of the energy generated by the SPV system is utilised to meet the energy requirement of daytime loads and excess energy is fed to the grid. The schematic of this configuration is shown in Figure 35.

Figure 35 : SPV schematic for grid-connected with net-metering and excess energy export



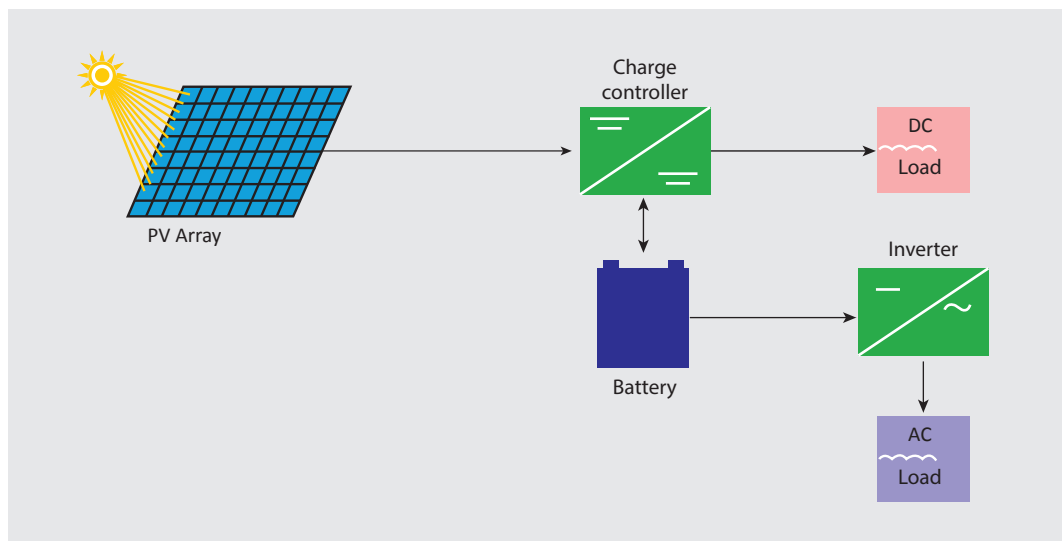
3. **Off-grid system with grid back-up power:** This is a modification of the grid-connected configuration. The building has two parallel power supplies, one from the solar PV system and another from the grid. The two power supplies are combined to meet the total electricity load of the building. However, in this case, the grid only acts as a back-up power source and there is no provision for exporting excess generation to the grid. A battery bank is provided for storing the excess generation from the solar PV system. There is an option to switch to grid-connected configuration with minimal cost. The schematic of the configuration is presented in Figure 36.

Figure 36: SPV schematic for hybrid system (system with grid back-up power)



4. **Stand-alone (off-grid) solar PV system with dedicated loads:** In this configuration, the solar PV system is not connected to the grid. Electricity generated from the solar PV system is used for either meeting certain dedicated loads in the daytime or storing the energy by charging the batteries for night-time loads. Electricity for water pumping and lifts during daytime can be directly supplied by the solar PV system. The energy stored in the batteries can be used to meet the requirement of lighting and lifts during the night. This configuration requires a substantial battery bank to store the electricity for night-time. The schematic of this system is shown in Figure 37.

Figure 37: SPV schematic for stand-alone off-grid configuration

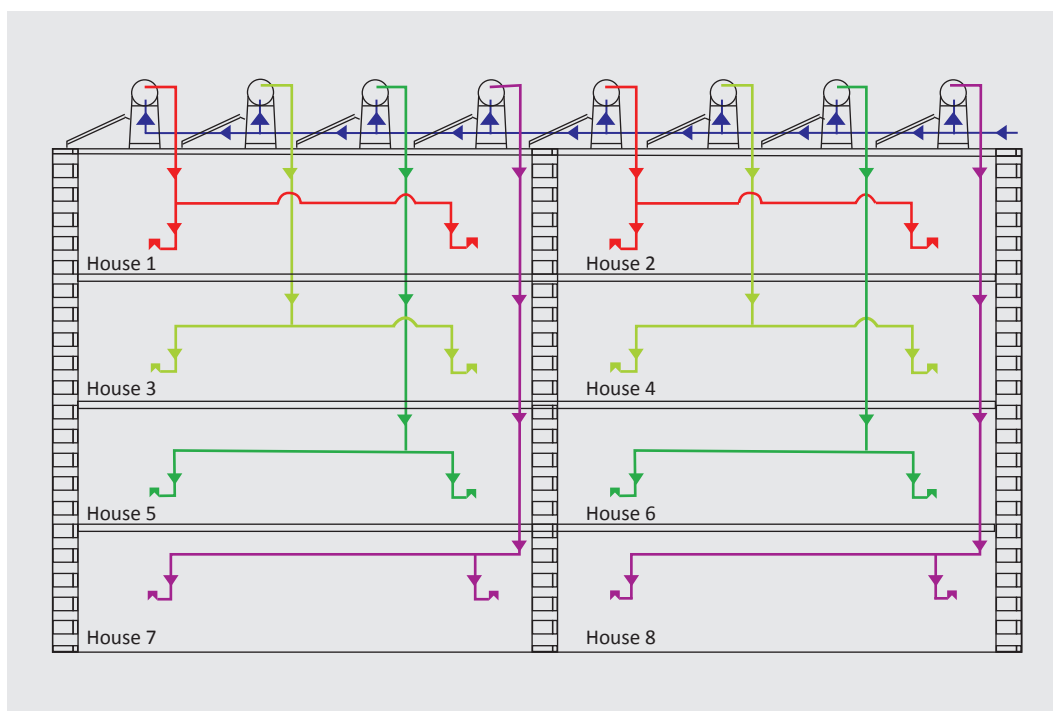


A 2.2 Solar water heating system integration models in buildings

The SWH systems are integrated in buildings in two configuration ways. They are

1. **Individual SWH systems:** This type of configuration can be found in all types of residential buildings. In this configuration (Figure 38), a separate solar water heating system for each flat is installed on the roof of the building. A hot water pipeline is individually drawn for each flat. The advantage of this configuration is that (a) it ensures equal distribution of hot water to each of the flats, and (b) maintenance and service of the individual system is borne by each flat. However, this configuration requires more space on the terrace because a circulation area needs to be left between two solar systems. Also, the length and cost of the hot water piping are relatively high, and providing hot water at requisite temperatures to the flats situated on the lower floors is also difficult due to longer hot water pipe length and related higher pipe heat losses.

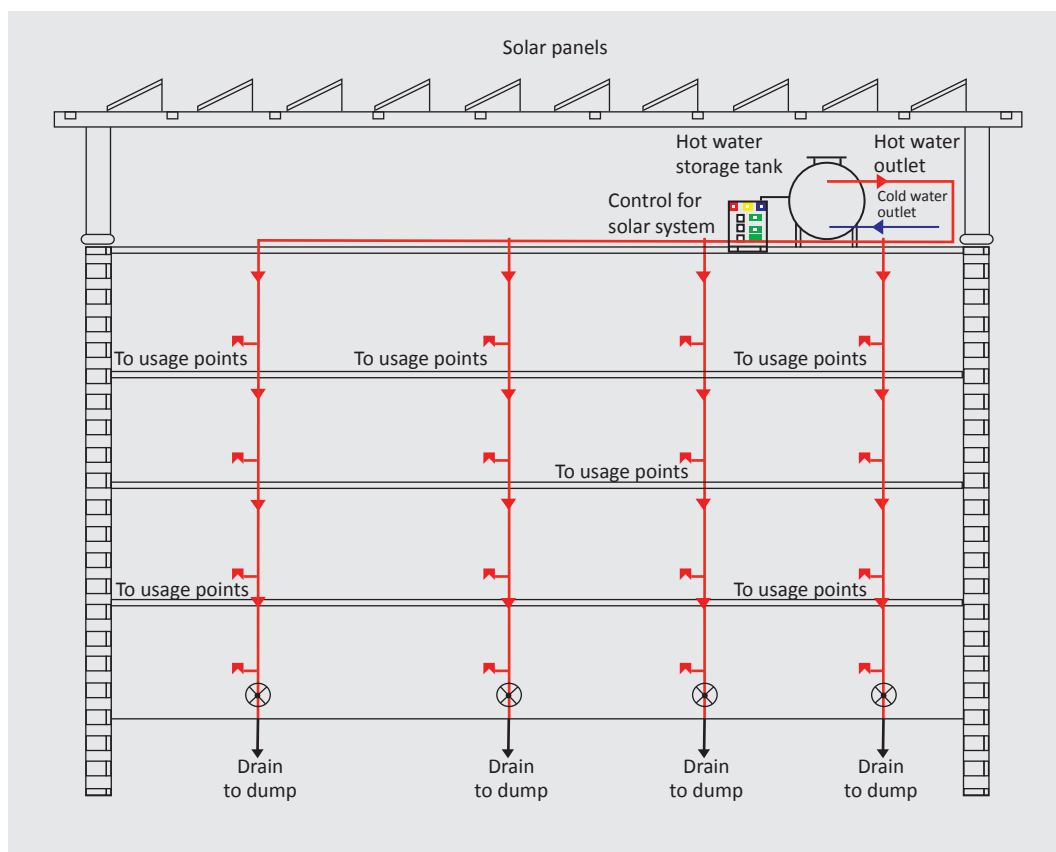
Figure 38: Schematic for individual SWH system for each flat³⁹



2. **Centralised SWH systems:** In this configuration, a large solar water heating system that can provide hot water to the entire building is installed on the roof. The hot water from the system is supplied through a common pipe network. This configuration occupies less area on the roof than the individual type configuration, and is found more in multi store residential buildings (please see Figure 39) and commercial buildings like hospitals, hotels, etc. However, in the community type configuration, proper arrangements need to be made for (a) efficient back-up heating, (b) ensuring equal hot water sharing among the flats, and (c) ensuring instant hot water supply for the lower floors.

39. School of Energy Studies, University of Pune (August 2012): Guidelines on installation of solar water heating systems in high rise buildings, Published under MNRE-UNDP-GEF Global Solar Water Heater Project

Figure 39: Schematic for centralised SWH system⁴⁰



These two types of configurations can have an arrangement of individual back-up systems and centralised back-up systems to meet the heating requirement when solar radiation is available or not sufficient to produce required demand.

Footnotes

- 1 Concentration ratio is defined as the aperture area divided by the receiver/absorber area of the collector
- 2 $CUF = \text{Actual solar energy generation per year (kWh)} / \text{Installed capacity (kW}_p\text{)} * 24 * 365$
- 3 $PR = \text{Actual solar energy generation per year (kWh)} / \text{theoretical energy generation (kWh)}$

40. School of Energy Studies, University of Pune (August 2012): Guidelines on installation of solar water heating systems in high rise buildings, Published under MNRE-UNDP-GEF Global Solar Water Heater Project

Of the total electricity consumption in year 2014-15 in India, residential and commercial buildings accounted for ~23% and ~8%, respectively. It is likely that there could be ten fold increase in electricity consumption in these segments in the next thirty years. While energy efficiency measures can reduce demand significantly, onsite renewable energy generation can help further reduce energy & electricity bills, dependence on the central electricity grid, reduce transmission and distribution (T&D) losses while generating clean energy at the same time. Direct onsite renewable energy use in buildings has significant potential and forms one of the key blocks within the larger move by India towards greater use of renewable energy.

This report looks at the various onsite renewable energy generation technologies available in India, their policy-regulatory framework and their experience in deployment through various case studies. Supplemented by interaction with various stakeholders in this sector, the report focuses on identifying the opportunities and challenges in realizing the potential of onsite RE generation and use in buildings in India.