PROJECT REPORT OF MAJOR - II

THERMO-ECONOMIC ANALYSIS OF CONCENTRATED SOLAR HEAT APPLICATIONS IN HOSPITALITY INDUSTRIES

Submitted in partial fulfilment of the requirement for the award of degree of

Master of Technology

In

Renewable Energy Technology

Submitted by

ASHISH YADAV

2K15/RET/03

Under the supervision of

Dr. RAJESH KUMAR (ASSOCIATE PROFESSOR)

Dr. J P KESARI (ASSOCIATE PROFESSOR)

Department of Mechanical Engineering

Delhi Technological University, Shahbad Daulatpur

Bawana Road, Delhi-110042, INDIA

July-2017

DECLARATION

I, hereby declare that the work which is being presented in this dissertation, titled **"THERMO-ECONOMIC ANALYSIS OF CONCENTRATED SOLAR HEAT APPLICATIONS IN HOSPITALITY INDUSTRIES"** towards the partial fulfilment of the requirements for the award of degree of **Master of Technology** with specialization in RENEWABLE ENERGY TECHNOLOGY from Delhi Technological University Delhi, is an authentic record of my own work carried out under the supervision of **Dr. Rajesh Kumar** and **Dr. J P Kesari,** Associate Professor, Mechanical Engineering Department, Delhi Technological University, Delhi.

The matter embodied in this dissertation record has not been submitted by me for the award of any other degree.

ASHISH YADAV
M.Tech (RET)
(2K15/RET/03)

CERTIFICATE

This is to certify that the work embodied in the dissertation entitled **"THERMO-ECONOMIC ANALYSIS OF CONCENTRATED SOLAR HEAT APPLICATIONS IN HOSPITALITY INDUSTRIES"** by Ashish Yadav (2K15/RET/03) in partial fulfilment for the award of degree of Master of Technology in Renewable Energy Technology, is an authentic record of student's own work carried out under my guidance and supervision.

It is also certified that the report has not been submitted to any other institute/university for the award of any degree.

Dr. Rajesh Kumar (Guide)
Associate Professor, M.E.D
Delhi Technology University, Delhi-110042

Dr. J P Kesari (Co-Guide)
Associate Professor, M.E.D
Delhi Technology University, Delhi-110042

ACKNOWLEDGEMENT

It gives me immense pleasure to acknowledge my indebtedness and a great sense of gratitude to **Dr. Rajesh Kumar and Dr. J.P. Kesari**, for providing me an opportunity to work on this very relevant topic. Their able guidance, sympathetic and encouraging attitude throughout the project work, is acknowledged with a core of my hearts. In spite of their busy schedule, they could find time to provide me precious guidance.

I express my deepest gratitude to Prof R.S. Mishra, Professor and HOD, department of Mechanical Engineering, DTU. Prof R.S. Mishra had been our minor-2 in charge and supervisor; he always encouraged us and advised us to keep in constant touch with our mentors. He is a great source of knowledge and he is always working hard to do best for his students.

ASHISH YADAV

M.Tech (RET)

(2K15/RET/03)

ABSTRACT

Indian hospitality industries are under considerable strain to move from fossil fuel to clean energy technology. Hospitality industry is one of the major industries in India which have huge energy requirements in the form of both electrical and thermal. Hospitality industry involves various heat processing steps like in kitchen, for laundry and for bathing. The use of an appropriate solar thermal technology can have a positive impact on the energy and environment scenario of hospitality industry at a large. There are various solar thermal technologies including CST technologies that are available for hospitality industries. Objective of the present work is to design solar paraboloid dish based heat system for Indian hospitality industries for cooking, laundry and bathing purpose. A solar paraboloid dish is designed with dual axis tracking for better efficiency. Concentrating characteristics of the sunlight have an important effect on the optical-thermal conversion efficiency of solar concentrator and the application of the receiver. Result of the performance of 14 m diameter solar paraboloid dish at Delhi site has been compiled with major parameters like physical dimensions of the paraboloid dish, energy generation potential of single dish and complete array, total energy requirement for plant, integration within plant, costing of the installation of SIPH system and its economic analysis in the form of payback period.

The solar paraboloid based SIPH system can be installed at various hospitality industrial plants with region of high DNI values to make hospitality industry more environment friendly by reducing green house gas (GHG) emissions. Also SIPH system will help companies' dependence of quickly depleting fossil fuels for thermal energy requirements and save them from highly fluctuating fossil fuel prices. Finally the technical feasibility of the solar process heating system for the industry has been proved along with its economic feasibility.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

NOMENCLATURE

CEA	: Central Electricity Authority
DNI	: Direct Normal Irradiance
GHI	: Global Horizontal Irradiance
IEA	: International Energy Agency
IREDA	: Indian Renewable Energy Development Agency
IRENA	: International Renewable Energy Development Agency
KWh	: Kilo Watt Hours
MNES	: Ministry of Non Conventional Energy Sources
MNRE	: Ministry of New and Renewable Energy
MTOE	: Million Tonnes of Oil Equivalent
MW	: Mega Watts
RET	: Renewable Energy Technology
UNDP	: United Nation Development Program
LPG	: Liquefied Petroleum Gas
CASE	: Commission for Additional Sources of Energy
MOP	: Ministry of Power
TERI	: The Energy Resource Institute

CHAPTER 1: INTRODUCTION

Energy is one of the real contributions for the financial improvement of any nation. On account of the creating nations, the energy segment expects a basic significance in perspective of the ever-increasing energy needs requiring colossal speculations to meet them. Energy can be classified into a few sorts in light of the accompanying criteria as follows.

• Primary and Secondary energy

• Commercial and Non commercial energy

• Renewable and Non-Renewable energy

Primary energy sources are those that are either found or put away in nature. Basic essential energy sources are coal, oil, petroleum gas, and biomass, (for example, wood). Other essential energy sources accessible incorporate nuclear energy from radioactive substances, warm energy put away in earths inside, and potential energy because of earth's gravity. The significant essential and auxiliary energy sources are appeared. Primary energy sources are generally changed over in mechanical utilities into secondary energy sources; for instance coal, oil or gas changed over into steam and power. Primary energy can likewise be utilized straightforwardly. Some energy sources have non-energy utilizes, for instance coal or flammable gas can be utilized as a feedstock in manure plant.

Commercial Energy is the energy sources that are accessible in the market at an fixed cost are known as commercial energy. By a wide margin the most essential types of commercial energy are power, coal and refined oil based goods. Commercial energy frames the premise of mechanical, farming, transport and commercial advancement in the present day world. In the industrialized nations, popularized fills are transcendent source for monetary creation, as well as for some family unit errands of all inclusive community. Illustrations: Electricity, lignite, coal, oil, flammable gas and so on. **Non-Commercial Energy** is the energy sources that are not accessible in the commercial advertise at a cost is delegated non-commercial energy. Non-commercial energy sources incorporate energizes, for example, kindling, dairy cattle excrement and rural squanders, which are generally accumulated, and not purchased at a cost utilized particularly in rustic families. These are additionally called customary energizes. Non-commercial energy is regularly disregarded in energy bookkeeping. For example: Firewood, agro squander in rustic ranges; sun based energy for water warming, power era, for drying grain, fish and natural products; creature control for transport, sifting, lifting water for water system, smashing sugarcane; wind energy for lifting water and power era.

Renewable energy is energy acquired from sources that are basically unlimited. Cases of renewable assets incorporate wind control, sun powered power, geothermal energy, tidal power and hydroelectric power. The most critical element of renewable power source is that it can be tackled without the arrival of hurtful toxins. Non-renewable power source is the regular petroleum products, for example, coal, oil and gas, which are probably going to exhaust with time.

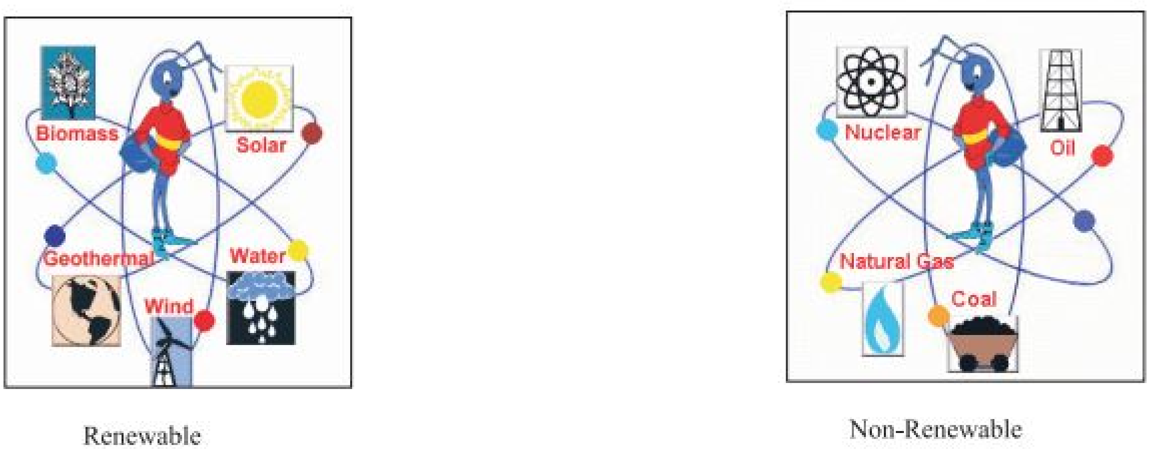

Figure1: - Renewable and non renewable sources of energy (source: - thinklink)

1.1 WORLD ENERGY SCENARIO

International organizations like international energy agency have published the world energy outlook 2016: global energy trends to 2040, focus on energy efficiency. Essential highlights of this report demonstrate the current trends and current energy utilization information of the world. Dissecting this date will help us to comprehend the present issues in the energy segment and connected issues with current energy situation. we will utilize this broke down information to discover valuable answers for this present issue which is manageable and environment friendly in nature.

1.1.1 GLOBAL ELECTRICITY GENERATION BY SOURCE

Electricity generation is characterized as electricity produced from non-renewable energy sources, atomic power plants, hydro plants (barring pumped capacity), geothermal systems, solar power, bio fuels, wind, and so forth. It incorporates power delivered in power just plants and in consolidated thermal and power plants. Greater part of energy still originates from coal and petroleum based power plants with an offer of 68% in total power era for the year 2015 which is identical to 16000TWh and more units created. Related CO_2 outflows with the petroleum derivative based era hotspot for the year 2015 was 13 gigatons. Following table gives 2015 versus 2040 situation of world power era based on various sources**[1]**:-

Table1: - Global electricity generation by source for 2015 vs 2040 (source: - IEA)

Source	**Global electricity generation by source (2015)**	**Global electricity generation by source (2040)**
Renewable	6000	13500
Coal	10560	11800
Gas	4800	9000
Nuclear	2600	4500
Oil	850	1250

Following table demonstrates that after coal and petroleum, renewable power source and nuclear energy sources are significant sources utilized for worldwide for power era with an offer of 22% and 9% respectively.

Following pie chart gives the percentage of various sources in global situation:-

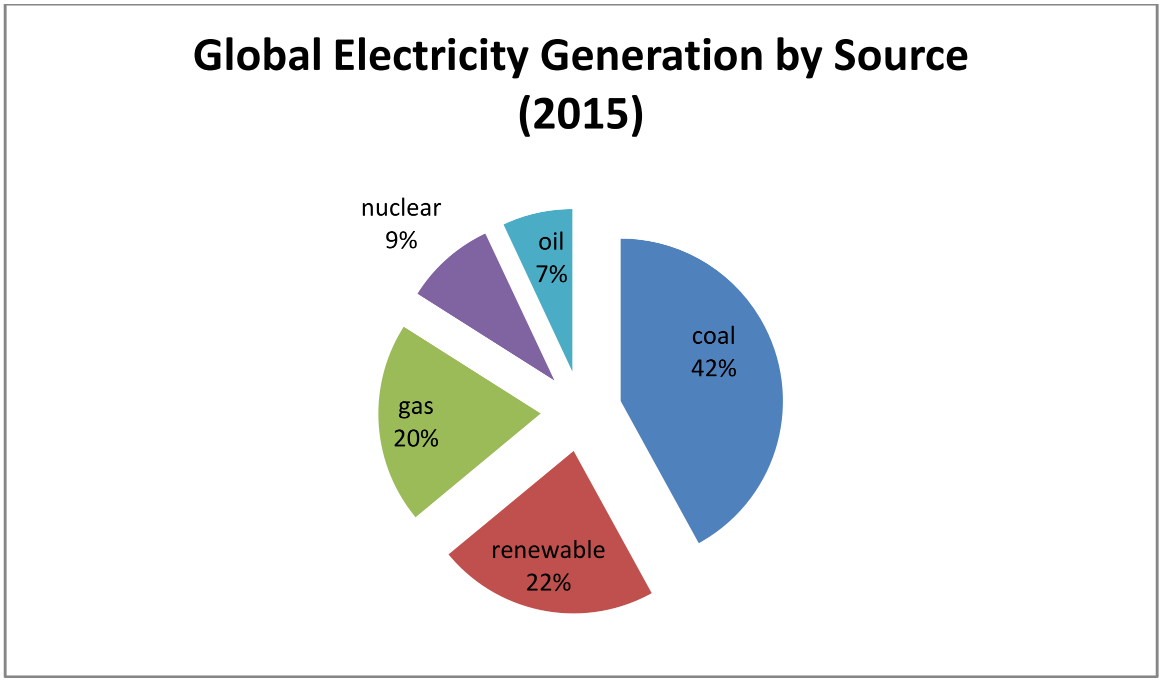

Figure2: - percentage share of different energy sources 2015 (source: - IEA)

Likewise high offer of coal and petroleum based power sources are specifically identified with abnormal state of CO_2 emissions every year. From the most recent two decades, CO_2 emissions have expanded from 6 Gt in 1990 to 13.50 Gt in 2016 i.e. greenhouse gases emissions have multiplied with add up to power produced from 11000TWh in 1990 to 24000 TWh in 2016. This demonstrates in most recent two decades just non-renewable energy source based sources were produced all throughout the world at the quick rate bringing about the issue of the world-wide temperature boost and environmental change. Following table demonstrates the connection between carbon dioxide emissions and power produced from 1990 to 2030:-

Table2: - year wise carbon dioxide emissions and electricity generation (source: - IEA)

Year	**CO_2 Emissions (Gt)**	**Electricity generation (1000TWh)**

1990	6.40	10.8
1995	7.50	11.8
2000	9.00	15.7
2005	11.00	19.6
2010	11.80	20.7
2015	12.50	23.0
2020	13.00	27.0
2025	12.50	30.5
2030	12.50	33.4

Post Paris climate change summit in 2015, the entire world has chosen to lay more accentuation on carbon-free sources of era for power purpose to have sustainable improvement of the entire world. Therefore it is clear from Table 2 that after 2015 till 2030 the CO_2 outflows have turned out to be consistent at around 12.50 Gt or all the more yet power era has expanded from 24000TWh in 2016 to 33000 TWh in 2030. This steady CO_2 discharge demonstrates that new era sources principally originated from renewable like hydro, sun oriented, the wind and others atomic and gas based sources. The following graph gives the comparison between add up to power generation by various source for the year 2015 versus 2040:-

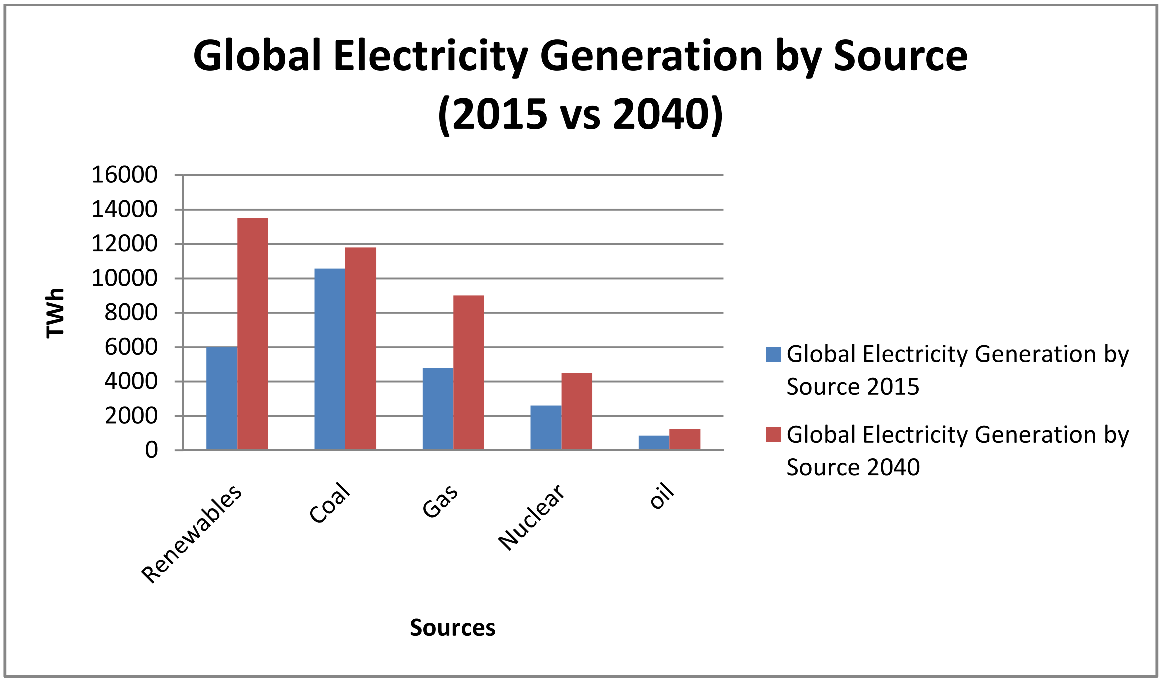

Figure3: - global electric generation for year 2040 (source: - IEA)

Power generation from sustainable power sources have changed from 6000TWh in 2015 to 13500TWh in 2040 i.e. it has moved toward becoming twice from 2015. Percentage share of non-renewable energy source based era has gone down from 67% in 2015 to 55% in 2040 and in the meantime sustainable power sources has gone up from 22% in 2015 to 34% in 2040 which demonstrates that 12% of petroleum derivative utilization in next 25 years to 12% more sustainable power source use in next 25 years. This notable move in world energy scenario is straightforwardly connected with adjustment of world CO2 outflow from 2015 to 2030 as appeared in this figure:-

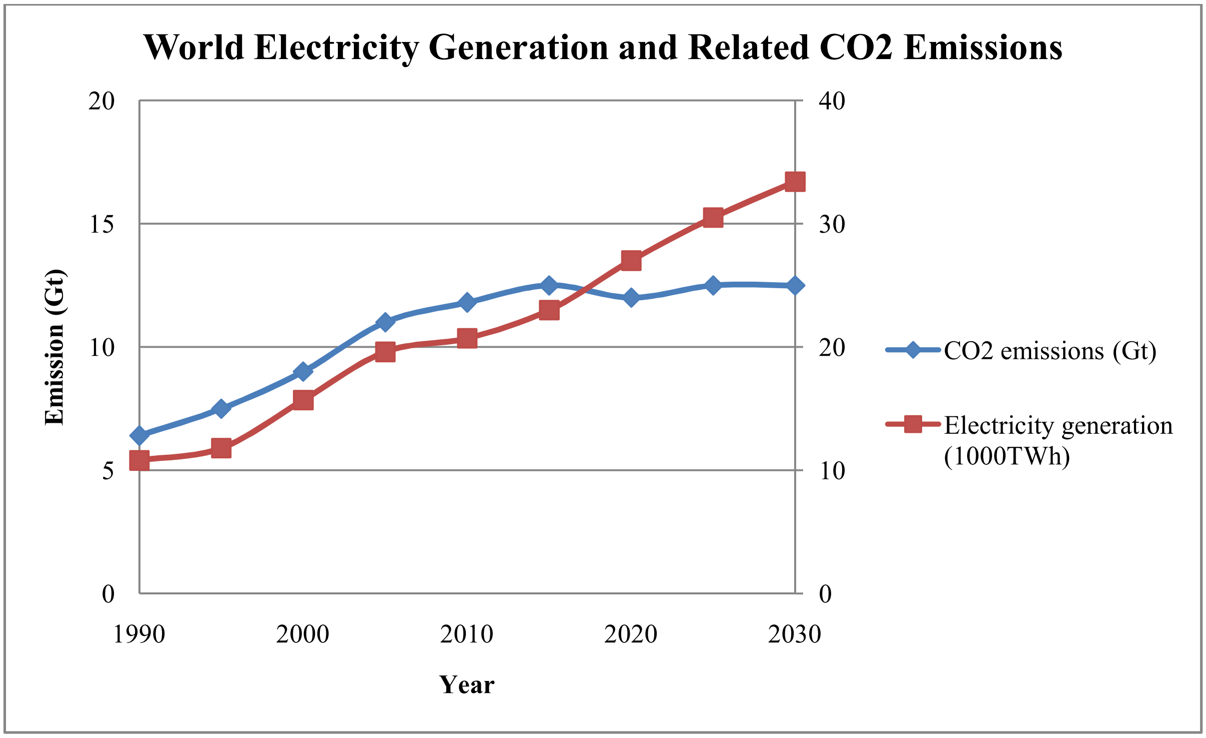

Figure4: - world electricity generation and related CO_2 emissions (source: - IEA)

1.2 INDIA'S ENERGY SCENARIO

India positions 6th on the globe in all out energy utilization, while over 70% of its primary energy needs are being met through imports, primarily as unrefined petroleum and gaseous petrol. Going to the power era in the nation, India has expanded introduced control limit from 1362 MW to more than 112,058 MW since independence and exhilarated more than 6,00,000 villages. This accomplishment is noteworthy however not sufficient. The power utilization per capita for India is only 566 kWh and is far beneath most different nations or areas on the planet. Despite the fact that 85% of villages are considered electrified, around 57% of the rural families and 12% of urban households, i.e. 154 million families in the nation, don't get approached by power.

Power demand in India has a percentage share of 6% in global energy demand for the year 2015. With 19% of aggregate total populace, per capita, energy utilization is still low at 33% of world normal which takes into consideration a solid energy demand development. The primary explanation behind this low energy utilization is extensive populace i.e. 220 million individuals still stays without power as they are distant operation from power grid. The following figure gives the comparison between per capita energy utilization amongst India and the world**[2]**: -

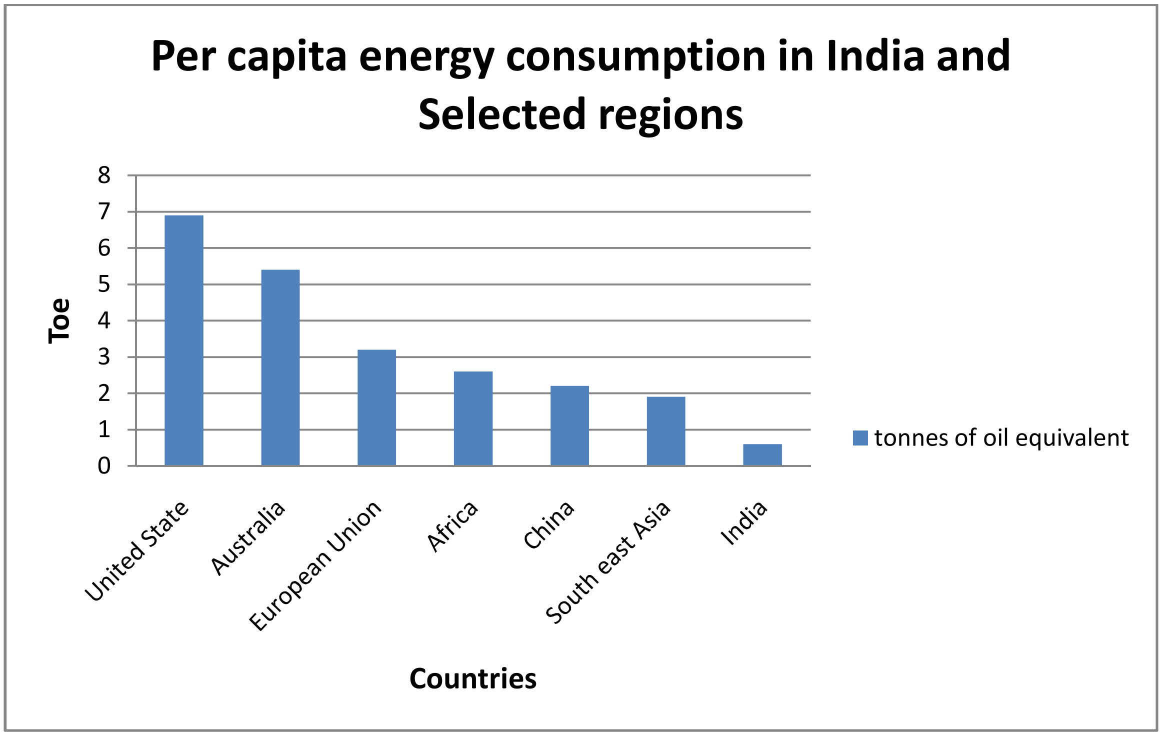

Figure5: - per capita energy consumption in India and selected regions (source: - IEA)

The power generation focus of fossil fuel based generation for the year 2017-18 has been settled as 1229.400 Billion Unit (BU). i.e. development of around 5.97% fossil fuel based power plants capacity of 1160.141 BU for the earlier year (2016-17). Coal and petroleum-based generation during 2016-17 was 1160.141 BU when contrasted with 1107.822 BU generated during 2015-16, speaking to a development of around 4.72 %.

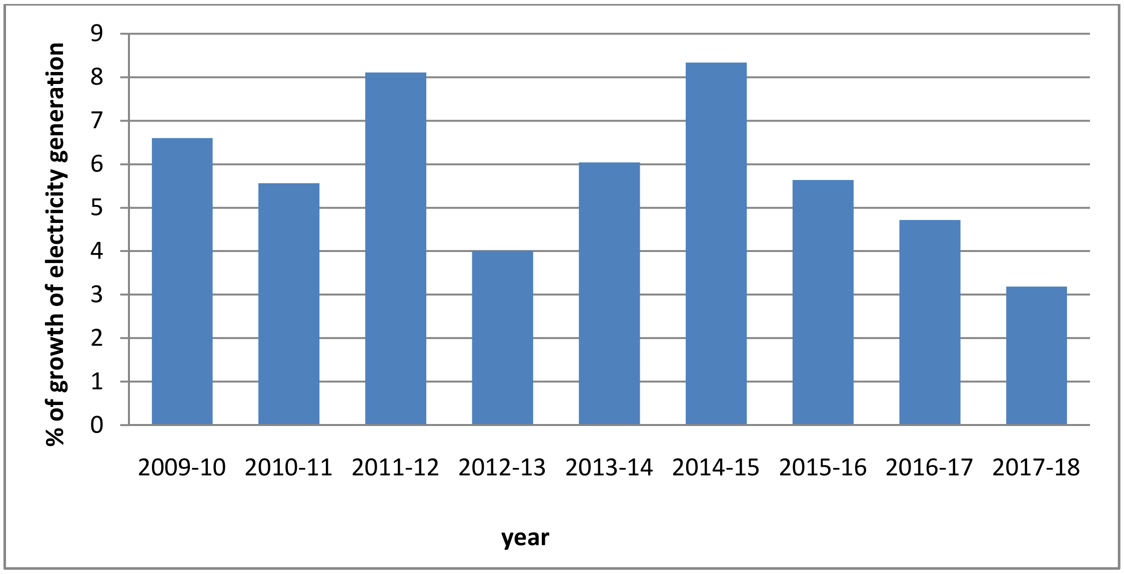

Figure6: - growth of electricity generation in India (source: - IEA)

1.2.1 INDIA'S TOTAL INSTALLED POWER GENERATION CAPACITY

India's total installed power generation capacity has crossed the 300-GW mark, which includes 57 GW of renewable energy sources, including solar and wind. India's total power generation capacity was 329,205 MW as on April 30, 2017. The thermal power is delivered in Coal, Gas and Diesel based power plants. Nuclear power is delivered in nuclear power plants. Inexhaustible power incorporates Hydel plants and other sustainable sources, for example, wind, biomass, bagasse, waste to-energy and sun based power. Following pie chart shows the percentage share of each power generating sector in which thermal contributes 67%, renewable energy contributes 17%, hydro based plants gives 14% and nuclear has 2% of share.

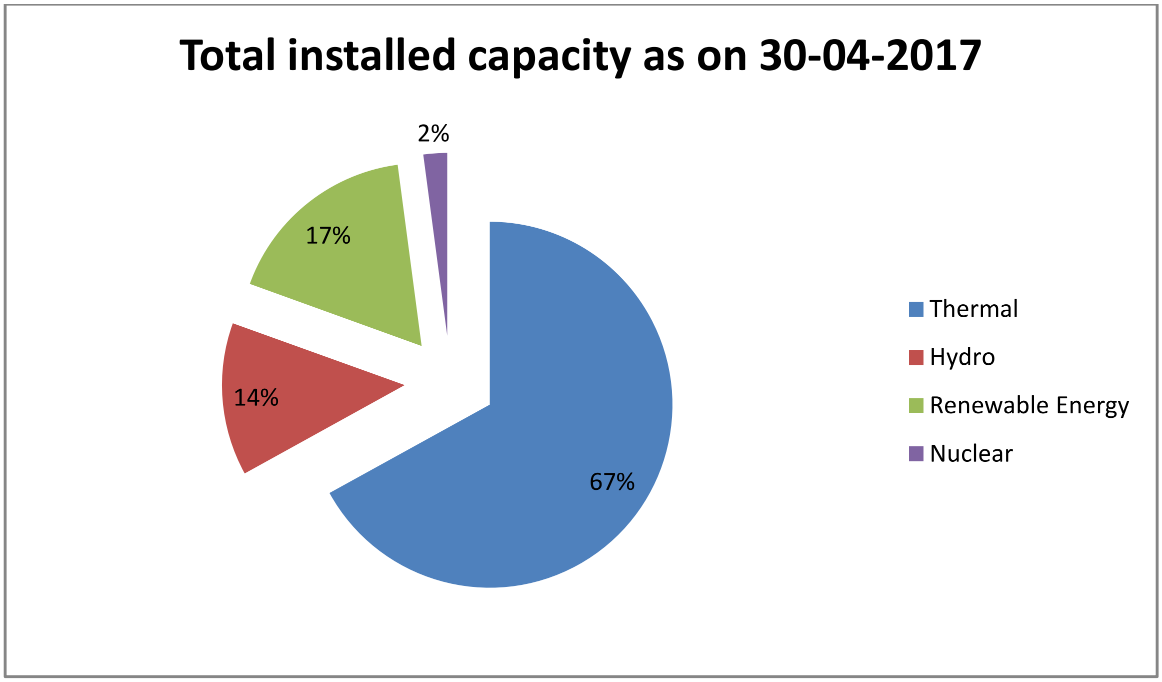

Figure7: - total installed capacity of India (source: - CEA)

At present coal based power plants contributes 59% of total installed capacity, natural gas based plants contributes 7.7 % and diesel based plant has a share of 0.3%. A table is demonstrated below to show the total installed capacity in MW from thermal, hydro, nuclear and renewable as follows:-

Table3: - total installed capacity of India in MW (source: - CEA)

Fuel		MW	% of Total
Total Thermal		2,20,570	67.0%
	Coal	194,403	59.1%
	Gas	25,329	7.7%
	Oil	838	0.3%
Hydro (Renewable)		44,594	13.5%
Nuclear		6,780	2.1%
RES* (MNRE)		57,260	17.4%
	Total	**329,205**	

Out of 329,205 MW of power generation 81,167 MW is generated by state owned power plants, 104,447 MW is generated by central government and rest 143,590 MW is generated by private sector. Following table shows the percentage share of three sectors:-

Table4: - percentage share of three sectors

Sector	MW	% of Total
State Sector	81,167	24.7%
Central Sector	1,04,447	31.7%
Private Sector	143,590	43.6%
Total	**3,29,205**	

1.2.2 PRIMARY ENERGY DEMAND IN INDIA BY FUEL

70% of the Indian energy demand is filled by coal and petroleum products because of ascend in utilization of coal with an share of 44% of overall energy demand of 775 MToe for the year 2015. On the other hand demand for bio energy i.e., strong biomass like fuel wood, straw, charcoal, or compost has diminished as family units have moved to LPG for cooking reason. Oil utilization is for the most part for transportation segment with diesel having 70% share in the oil sector. Natural gas has little offer of 6% in energy mixed utilized predominantly for power generation and fertilizer enterprises. Hydropower, atomic power, inexhaustible sources like wind, sun based, geothermal is utilized at little scale in electricity sector. Following pie chart gives the present situation of India vitality mix:-

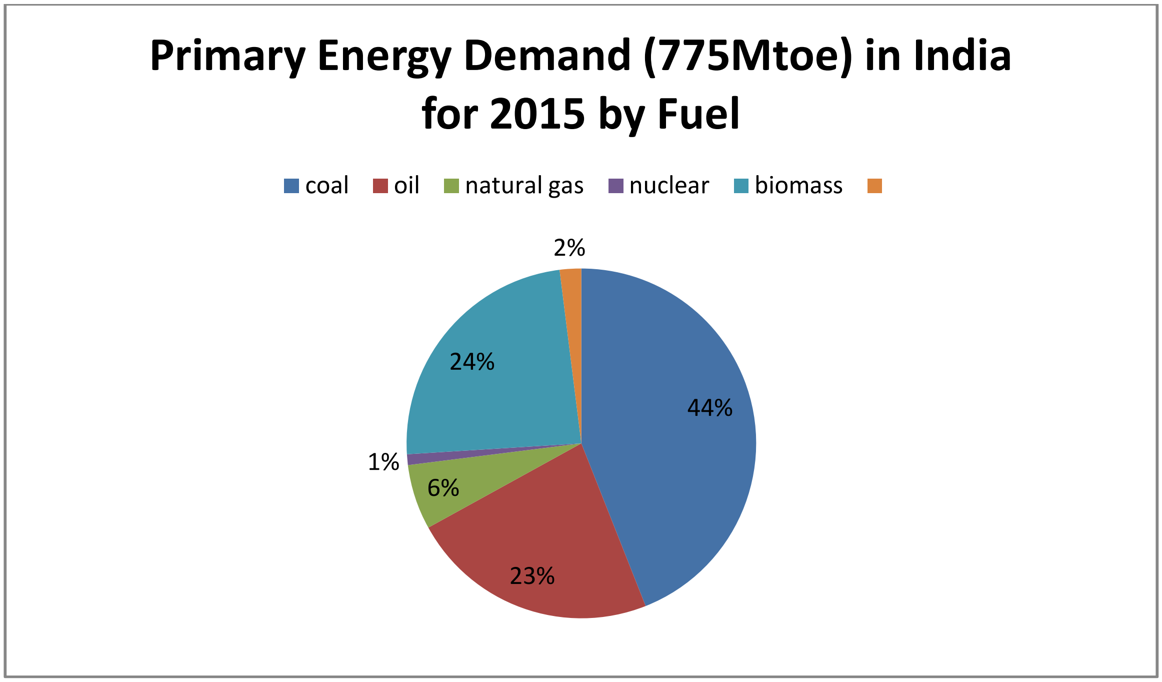

Figure8: - primary energy demand in India by fuel (source: - IEA)

1.2.3 FOSSIL FUEL RESERVE IN INDIA

Coal overwhelms the energy blend in India, adding to 55% of the aggregate essential energy creation. Throughout the years, there has been a stamped increment in the offer of petroleum gas in essential energy generation from 10% in 2015 to 13% in 2015. There has been a decrease in the offer of oil in essential energy generation from 20% to 17% amid a similar period.

COAL

Coal Supply in India has colossal coal saves, no less than 61,407 million tons of demonstrated recoverable stores. This adds up to very nearly 12% of the world stores and it might keep going for around 94 years at the present Reserve to Production (R/P) proportion. Global coal reserve estimated 8,91,531 million tonnes by the end of 2015 with reserve to production ratio is 110 years Conversely, the worlds demonstrated coal stores are relied upon to last just for a long time at the present R/P proportion. Reserve/Production (R/P) proportion If the stores staying toward the finish of the year are partitioned by the creation in that year, the outcome is the period of time that the rest of the stores would last if generation somehow managed to proceed at that level. India is the fifth biggest maker of coal and lignite on the planet. Coal generation is packed in these states (Andhra Pradesh, Bihar, Uttar Pradesh, Orissa, Madhya Pradesh, Maharashtra, Jharkhand, West Bengal).

OIL

India is the fourth-biggest buyer and net merchant of unrefined petroleum and oil based commodities on the planet after the United States, China, and Japan. India's oil based good request achieved about 3.7 million barrels for each day (bbl/d), far over the nation's around 1 million bbl/d of aggregate fluids creation. The majority of India's request is for engine gas and gasoil, powers utilized for the most part in the transportation and mechanical divisions, and for lamp fuel and LPG in the private and business segments. Shoppers get huge endowments for retail buys of diesel, LPG, and lamp oil, putting upward weight on general oil request. Inadequate interest in growing more unrefined petroleum and fluids generation has made creation develop at a slower rate than oil request. Global proven oil reserve is estimated 238 billion tonnes with R/P – 52.5. India had only 0.3% share of the world reserve i.e. 0.8 billion tonnes with reserve to production ratio of 17.6 years. The majority share of India's around 0.8 billion tonnes in oil stores are situated in the Bombay High, upper Assam, Cambay, and Krishna-Godavari.

NATURAL GAS

Natural gas represents around 11.2% of energy utilization in the nation. Global proven gas reserve estimated 182.6 trillion cubic meters. Reserve to production ratio is estimated as 52.6 years. Iran has the largest share of the reserve with 18.2% and R/P- 100years. India has only 0.9% share of the world reserve with R/P – 45years. India did not import natural gas until 2004, when it started to import liquefied natural gas (LNG). Since India has not possessed the capacity to deliver a satisfactory supply of local gaseous petrol and has been not able make adequate flammable gas pipeline framework on a national level, it progressively depends on imported LNG to take care of residential demand till 2004. But after 2004 many companies looked after supply and production of natural gas in India and its recognizable now.

NUCLEAR POWER

Apsara research reactor was the India's and Asia's first nuclear reactor. India's residential uranium stores are little and the nation is reliant on uranium imports to fuel its atomic power industry. Since March 2011, substantial stores of uranium, has been found in the Tummalapalle belt and in the Bhima bowl at Gogi in Karnataka by the Atomic Minerals Directorate for Exploration and Research (AMD) of India. The Tummalapalle belt uranium holds guarantees to be one of the main 20 uranium saves disclosure of the world. So far 44,000 tons of common uranium has been found in the belt. By the end of 2016, India has 22 nuclear reactors in working in 8 nuclear power plants, having an installed capacity of 6780 MW. India now imagines expanding the commitment of nuclear energy to general power era limit from 3% to 9% within 25 years. By 2020, India's installed nuclear power generation capacity will rise to 20 GW.

HYDROPOWER

The Government of India has taken numerous approach activities for feasible hydro-control improvement. In 2008, the legislature turned out with a Hydro Policy with a target to accomplish the usage of these ventures. The middle and many states have started hydro extends through PPP to draw in speculators for the improvement of water assets in a situation neighbourly way and to create income while guaranteeing venture reasonability. India is the seventh biggest maker of hydroelectric power on the planet positioning third worldwide in the aggregate number of dams. India's installed capacity of hydroelectric capacity is 42,783 MW or 14.35% of its total power generation capacity.

BIOENERGY

The current energy situation in India today demonstrates a developing reliance on traditional types of energy, around 32% of the aggregate essential energy utilize is as yet utilizing biomass, and over 70% of the nation's populace relies on it for its energy needs, making it a key player in energy era. Bioenergy is renewable energy which is available from materials produced from biological sources. The total installed capacity of biomass based power is estimated to be about 2600 MW (inclusive of off grid). Out of the total, bagasse based power generation has about 1400 MW, followed by combustion-based biomass power production of about 875 MW and then by biogasification of about 140 MW.

WIND AND SOLAR ENERGY

Renewable energy is drastically increasing in India to reach Re-Invest 2015 target of 175 GW by 2022. Wind and solar power are major factors to achieve this target set by Indian government with 100GW and 60GW respectively. India is ranked 4^{th} in wind power installed capacity in the world with 27GW as of 2017 and in solar power its capacity is 7GW as of 2017. Out of 100GW, 40GW target has been setup for roof top which help in reducing the transmission and distribution losses. Solar energy certainly has come a long way in being a reliable source of energy in its own right.

1.3 INDIAN HOSPITALITY INDUSTRIES

Hospitality sector in India has created massive business openings and is an indispensable wellspring of outside trade for the nation. The hospitality industry contributed Rs 2.62 trillion (US$ 36.21 billion) or 7.8% of GDP in 2015.The figures are required to ascend to Rs 4.44 trillion (US$ 72.19 billion) by 2024.The income from domestic tourism is probably going to increase by 8.35% in 2017 when contrasted with 5.18% a year back, as indicated by the World Travel and Tourism Council (WTTC) **[3]**. The Indian hospitality sector has been developing at a aggregate yearly development rate of 14.12% consistently including huge measure of remote trade to the economy. The Travel and Tourism Competitiveness Report of 2015, distributed by World Economic Forum, India, expressed that the positioning of India is eleventh in the Asia Pacific area and 65th in the World Travel and Tourism Competitiveness Record 2015. According to the Niti Aayog, the segment makes a bigger number of employments per million rupees of speculation than any other segment of the economy. It is equipped for giving work to a wide range of occupation searchers, from the untalented to the specific, even in the remote parts of the nation. The sector"s work era potential has likewise been highlighted by the World Travel and Tourism Council (WTTC), which says Indi’s travel and tourism division is relied upon to be the second-biggest boss on the planet, utilizing around 52 lac individuals, specifically or by implication by 2019.

India is anticipated to be the quickest developing country in the hospitality segment in the following five years, timing more than 20% picks up every year through 2017, as per a review directed by SRI International. Some of the major recent developments in the hospitality sector in India are as follows**[4]**:-

- JW Marriott plans to have 175-200 hotels in India over the next four years
- Accor Hotels India has adopted a ‘born in France, made in India’ approach to increase its properties in India, which has reached a total of 45 hotels and is expected to increase to 55 hotels by 2017.
- Global hospitality major Carlson Rezidor Hotel Group, which is also the largest foreign hotel brand in India by number of hotels, plans to increase its total count to 120 hotels in India by 2020.
- Hyatt Hotels Corporation has outlined plans of bringing its Hyatt Centric brand to India soon along with three new hotels in Kochi, Rameswaram and Hyderabad by 2017.

Major players in Indian hospitality industry are as follows:-

- The Ashok Hotel
- The Imperial Hotel
- Taj palace
- The Oberoi
- Hotel de l'Orient
- Bissau Palace Hotel
- Devigarh, Udaipur
- Lake Palace, Udaipur
- Lalgarh Palace, Bikaner
- Rambagh Palace, Jaipur
- Umaid Bhawan Palace, Jodhpur
- Accord Metropolitan hotel
- Bungalow on the Beach hotel
- Hilton hotels
- Hotel d'Angeli's, Chennai
- Hyatt Regency

- JW Marriott hotel
- Le Royal Meridien
- The Leela Palace
- The Park
- Radisson Blu Hotel
- The Elgin Hotel
- Great Eastern Hotel

The industry is relied upon to produce 2.3 million occupations The Ministry of Tourism arrangements to enable the business to take care of the expanding demand of talented and prepared labour by giving cordiality training to understudies and in addition ensuring and updating abilities of existing specialist organizations.

1.4 POTENTIAL OF SOLAR PROCESS HEAT IN INDUSTRIES IN INDIA

Industrial process heat demand of various industrialized nations like USA, European Union is up to 40% of total energy demand of the country. This energy consumed is mainly supplied in form of electricity, natural gas, oil or coal. Pattern of energy consumption in developing countries like India is 39% of total energy is consumed in industrial sector followed by 32% in transportation sector, rest 20% and 10% in residential and agricultural sector. Following figure gives the pattern of energy consumption for developing countries like India: -

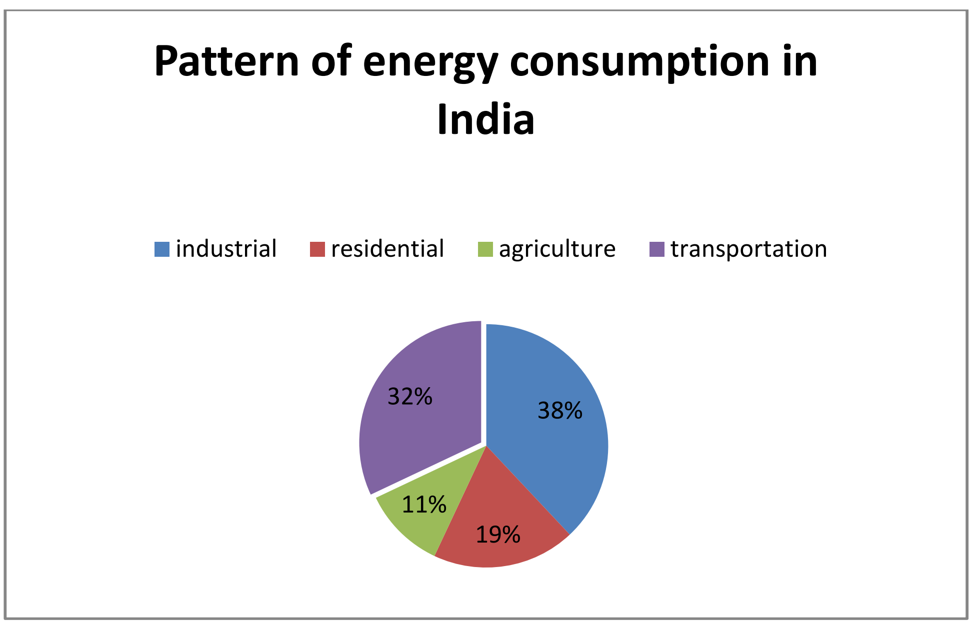

Figure9: - pattern of total energy consumption in India (source: - Niti aayog)

Quality and quantity of energy required for industry depends upon temperature levels of that industry. Size of SIPH system required also depends upon site solar radiation, process heat requirement, load profile, etc. Also solar energy can meet only a share of process heat demand in industry due to some limitations like unreliability of solar radiation and available, user load profile, land is also limited for a given industry. Coverage of part of process heat demand by solar energy is known as solar fraction which can go maximum up to 40% in most cases. Hence most of the SIPH system requires backup boiler. Hence solar energy as industrial process heat demand has a great potential in industry requiring energy from coal, oil or natural gas.

Following table gives the details of various industrial sectors mentioned above along with major industrial processes requiring thermal energy: -

Table5: - examples of medium temperature industrial process (source: - CSH)

Industry	**Process**
Food processing & dairy	Chilling/ cold storage, cooking, extraction, baking, pasteurization, sterilization, bleaching , drying etc.
Breweries	Boiling, mashing, cold conditioning, fermentation etc
Rubber	Heating, digestion, vulcanizing
Pulp & paper	Pulping, digestion & washing, bleaching, evaporation & softening
Tobacco	Steam conditioning, drying & softening
Electroplating	Post plating treatment, water heating, drying etc
Pharmaceutical	Distillation, drying, evaporation, fermentation, injection & moulding
Textile (Spinning & weaving, Finishing)	Preparing wraps, sizing, de-sizing, scouring, bleaching, mercerizing, dyeing, drying & finishing
Chemical & Fertilizers	Distillation, effluent treatment, primary reforming, ammonia synthesis, CO_2 removal,

	methanation, steam stripping
Refining	Desalting, cooking, thermal cracking, cleaning, wastewater treatment
Ceramic tile & pottery	Beneficiation, drying, presenter thermal processing, glazing
Desalination	Multiple effect distillation, multi stage flash distillation
Plaster of Paris, Steel re-rolling, Cement, Mining	Augmenting steam to boilers, boiler feed water heating
Education / Religious Institutions	Cooking, laundry
Hotels, Hospitals, Offices, Malls	Air-conditioning, hot water for bathing, laundry
Engineering, Automobile Industry	Component washing, de-greasing, metal treatment bath heating, paint drying
Chemical Process Industry	Boiler feed water heating, other heating operations, drying, distillation and evaporation, extraction
Food Processing	Drying, distillation and evaporation, extraction
Pulp & Paper Industry	Kraft pulping, effluent treatment, bleaching
Textile Industry	Mercerizing, drying, finishing

CHAPTER 2: LITERATURE REVIEW

2.1 LITERATURE REVIEW

Martin haagen et. al [5]: designed and installed first SIPH system in Jordan at RAM pharmacy based on linear Fresnel reflector [LFR] solar thermal technology. Principle of direct steam generation was applied. Pharma sector plays an important role in GDP of Jordan i.e. around 20% but on the same time has large heat demand. High Direct Normal irradiance [DNI] values in Jordan and fluctuating fuel prices makes a Jordan industry an important market for solar industrial process heat applications. In pharma industry, 65% of the total energy demand is for heating, ventilation and air conditioning [HVAC]. Central steam generation system produces steam at 160^0C to 180^0C to supply all production processes. Fresnel collector modules are installed on the roof of factory with total aperture of $396m^2$ and 222 KW thermal peak capacity.

Oliver iglauer et. al [6]: solar industrial process heating system for sustainable automobile production was proposed. Solar process heat is used in paint shop for curing of automobile paint at 200^0C. Process heat is generated by using linear Fresnel collector based solar thermal technology. Utilizing renewable solar thermal energy can offset fossil fuel consumption up to 70%. Feasibility of the technology had been evaluated on paint shop of automobile factory in India where integration of solar industrial process heat system has reduced energy demand by 14000 MWh and reduction of 2800 tons of carbon dioxide. Payback time occurs within five years depending on irradiance conditions of the site.

Franz mauthner et. al [7]: production of malt and beer requires large amounts of thermal energy which is generally produced by burning fossil fuels. Process temperature required is in range of 25^0C to 105^0C. Solar thermal technologies based on evacuated tube collectors [ETC] are used to integrate solar process heat in production system. Large vessels receive hot pressurized water from solar thermal collectors where production process takes place. 30% solar fraction is achieved with annual generation of 1570 MWh thermal units by solar process heating system. In the above exercise a savings of 38000 tons of carbon dioxide emissions is possible. 1620 m^2

gross collector area was installed at roof top with solar energy storage tank of 350 m^3 volume. Solar process heat is used for pasteurization of canned beer at temperature of 85^0C.

Thiago P Lima et. al[8]: high level of solar insolation in Brazil have made solar thermal energy with very high potential in Brazil industry to provide thermal energy. Most of industrial process needs hot water which can be easily obtained from flat plate collectors. Technical and financial feasibility of solar water heating system was studied for hospital laundry. System parameters like tilt angle of collector, water flow rate, area of collector and water storage tank size were optimized. Economic analysis was made on the basis of comparing life time saving due to solar water heating system against the current system based on natural gas burner. Finally results showed the consumption in natural gas reduced due to use of solar hot water system and making it a viable option.

Ricardo silva et. al [9]: use of parabolic trough solar thermal collector to generate process heat for food processing plant in Spain is studied. Solar industrial process heating system was able to produce saturated steam at 7 bar. SIPH system had parabolic trough collector solar field, thermal energy storage and backup steam boiler. Food sector has thermal energy demand in huge quantities with over 90% energy demand in low temperature to medium temperature range. Southern Spain region enjoys high DNI levels of 1700 kWh/m^2/year and above, thus allowing the use of concentrating solar thermal technology to reach high temperature levels with reasonable high efficiency. Solar thermal plant will be integrated with central steam supply system. Total process heat demand is 148MWh per year supplied currently by fuel oil based boiler.

Christian zahler et. al [10]: now a day there is huge pressure on automobile industry to make their manufacturing processes more environments friendly and sustainable in log term. Curing of car paint is the major manufacturing process with highest share in total energy consumption. Temperature in convection ovens are at 200^0C which is in range of concentrated solar technology such as Fresnel reflector (LFR). Pilot project system has been installed at Durr campus Germany which consists of 6 modules of LFR with total aperture area of 132 m^2. Fossil fuel fired backup boiler is used in case on non sunny hours to meet thermal demand of ovens fully. Heat is released in convective ovens through steam air heat exchanger. Energy consumption is around 700-900 KWh per car body which requires huge amount of fossil fuels to be burned.

Marco Calderoni et. al [11]: feasibility study of integration of solar thermal collectors in industrial processes in Tunisia is evaluated in this paper. Textile industry manufacturing processes are evacuated i.e. payback period was calculated and amount of fossil fuel substituted by solar energy was also estimated. Huge potential is already there for solar heat for industrial process in Tunisia as 30% of the total industrial heat demand is required at temperature between 100^0C and 400^0C which is in range of concentrating solar thermal technologies. Also highly subsidized fossil fuels in Tunisia have become major cause for low potential of solar thermal in industry. Main industrial processes in textile industry for solar thermal technology integration are dyeing and ironing. Dyeing process needs thermal energy at 98^0C.

A Ferin et. al [12]: design of solar industrial process heat plant for integration with dyeing process of Benetton facility in Tunisia. Total aperture area is 1000 m^2. Main aim is to optimize solar plant and sizing of other main components is also done. Dyeing process requires huge amount of energy. Hot water is required at 60^0C. Use of solar energy for process heating has a potential of saving of 100MWh annually. 30000 litres of hot water storage is also being built to increase share of solar energy in total thermal energy requirement. Also Government support in form of subsidy to solar thermal plant will help solar process heat market to develop further in Tunisia. Currently high subsidised fossil fuel mainly natural gas is major hindrance in growth of solar thermal Technology.

Lauterbach et. al [13]: process heat generation by solar thermal Technology has large potential but remains unexploited. Solar thermal system can achieve very large solar fraction for industrial applications. System set up can be very complex due to presence of different heat consumers, temperature sensors and Hydraulic circuits. Therefore to design and operate solar thermal system optimally, possible faults that can occur in the system are evaluated. Simulation model for solar process heat system is made and validated against actual setup based on data collected during project monitoring. Faults identified and their influence is evaluated on the system. Final result show that reduces load on system is influential and system yield can be maximised if all faults are eliminated. Important factors for plant optimisation are system efficiency, mass flow rate an temperature.

R J Fuller et. al [14]: research and development for solar industrial process heating system has been going on in Australia for last 30 years. Commonwealth science and industrial research organization (CSIRO) is carrying out all these activities. Future of SIPH looks very bright in Australia. For Australia to decarbonise its economy, huge growth of solar industrial process heating system is required at national level for those industries which use huge amount of fossil fuels for producing hot water. Author has reviewed the past installations of SIPH in Australia and analysed the results to find out problems to optimize the systems to be installed in future.

Wang et. al [15]: studied a three- model of parabolic dish-receiver system with argon gas as the working fluid is designed to simulate the thermal performance of a dish-type concentrated solar energy system. The temperature distributions of the receiver wall and the working gas are presented. The impact dimensional of the aperture size, inlet/outlet configuration of the solar receiver and the rim angle of the parabolic dish are investigated. The results show that the aperture size and different inlet/outlet configuration have a considerable impact on the receiver wall and gas temperatures, but the rim angle of the parabolic dish has negligible influence.

Ashmore et. al [16]: investigated the thermal performance of a cylindrical cavity receiver for an SK-14 parabolic dish concentrator is presented in this technical note. The thermal performance is evaluated using energy and exergy analyses. The receiver exergy rates and efficiencies are found to be appreciably smaller than the receiver energy rates and efficiencies. The exergy factor parameter is also proposed for quantifying the thermal performance. The exergy factor is found to be high under conditions of high solar radiation and under high operating temperatures. The heat loss factor of the receiver is determined to be around 4.6 W/K. An optical efficiency of around 52% for parabolic dish system is determined under high solar radiation conditions. This experimental setup can be used as teaching tool for people with little or no knowledge about solar dish concentrators due its simplicity and the basic mathematical formulations applied. Different types of receivers and different types of deep focal region parabolic dishes can also be tested with the experimental setup.

Reddy et. al [17]: studied combined laminar natural convection and surface radiation heat transfer in a modified cavity receiver of solar parabolic dish collector is presented in this paper. A two-dimensional simulation model for combined natural convection and surface radiation is developed. The influence of operating temperature, emissivity of the surface, orientation and the geometry on the total heat loss from the receiver is investigated. The convective heat loss from the modified receiver is significantly influenced by the inclination of the receiver whereas the radiation heat loss is considerably affected by surface properties of the receiver. The Nusselt number correlations are proposed separately for both natural convection and surface radiation based on large set of numerical data for a given range of parameters of practical interest. It is observed that the convection and radiation heat losses are found respectively 52% and 71.34% of the total heat loss at 0◦ inclination and 40.72% and 59.28% at 90◦inclination for the modified cavity receiver with an area ratio of 8 and 400 ◦C. The convection and radiation numerical procedure is validated with other models. The results obtained from the present numerical procedure are in reasonable agreement with other well-known open cavity models.

Reddy et. al [18]: analyzed analysis of solar dish modified cavity receiver with Cone, CPC and Trumpet reflectors is presented. Three-dimensional modeling is carried out to estimate the convective and radiative heat loss from the receiver for different angles of inclination and operating temperatures. Incorporating reflectors in the modified cavity receiver for second stage concentration, the natural convection heat losses are reduced by 29.23, 19.81 and 19.16%, respectively. The receiver with the trumpet reflector has shown better performance as compared to other configurations.

Reddy et. al [19]: presented techno-economic feasibility analysis of a 5MWe solar parabolic dish collector field is carried out for entire India covering 58 locations. The solar parabolic dish power plant configuration is investigated based on various parameters such as the spacing between dish collectors, land area required, percentage of the shadow and energy yield. The shadow profile around the dish throughout the year at various latitudes (8–35N) for various plant-operating hours is determined. In-line arrangement of the solar dish collector arrays is found to be a better choice in terms of the minimum land area required for setting up the power plant. The generalized correlations are developed for both east–west and north–south spacing distances as the function of latitude and plant operating hours. It is found that the configuration corresponding to the plant operating from 1 h after sunrise to 1 h before sunset with spacing distance in east–west direction equal to the shadow length after 2 h sunrise and in north–south direction equal to shadow length at noon for winter solstice gives the highest energy output with optimum land use. The minimum and maximum average annual power generation at Panaji and Tiruchirapalli are 7.25 GWh, and 12.68 GWh respectively. The minimum levelised electricity cost (LEC) for a stand-alone solar parabolic dish power plant with the clean development mechanism (CDM) is found to be INR 9.83 ($ 0.197, 1$ = INR 50) at Indore with payback period of 10.63 years withcost benefit ratio of 1.48. Based on the financial performance, most of the northern region locations and some of the western and southern region locations are found attractive for power generation by the solar parabolic dish power collector based on the direct steam generation, where direct normal irradiation (DNI) is more than 5 kWh/m2 day.

Wu et. al [20]: proposed a parabolic dish AMTEC solar thermal power system and evaluates its overall thermal electric conversion performance. The system is a combined system in which a parabolic dish solar collector is cascaded with an alkali metal thermal to electric converter (AMTEC) through a coupling heat exchanger. A separate type heat-pipe receiver is selected to isothermally transfer the solar energy from the collector to the AMTEC. To assess the system's overall thermal–electric conversion performance, a theoretical analysis has been undertaken in conjunction with a parametric investigation by varying relevant parameters, i.e., the average operating temperature and performance parameters associate with the dish collector and the AMTEC. Results show that the overall conversion efficiency of parabolic dish/ AMTEC system could reach up to 20.6% with a power output of 18.54 kW corresponding to an operating temperature of 1280 K. Moreover, it is found that the optimal condenser temperature, corresponding to the maximum overall efficiency, is around 600 K. This study indicates that the parabolic dish/AMTEC solar power system exhibits a great potential and competitiveness over other solar dish/engine system and the proposed system is a viable solar thermal power system.

Wu et. al [21]: presented a comprehensive review and systematic summarization of the state of the art in the research and progress in this area. The efforts include the convection heat loss mechanism, experimental and numerical investigations on the cavity receivers with varied shapes that have been considered up to date, and the Nusselt number correlations developed for convection heat loss prediction as well as the wind effect. One of the most important features of this paper is that it has covered numerous cavity literatures encountered in various other engineering systems, such as those in electronic cooling devices and buildings. The studies related to those applications may provide valuable information for the solar receiver design, which may otherwise be ignored by a solar system designer. Finally, future development directions and the issues that need to be further investigated are also suggested. It is believed that this comprehensive review will be beneficial to the design, simulation, performance assessment and applications of the solar parabolic dish cavity receivers.

Barlev et. al [22]: focuses on innovation in CSP technologies over the last decade. A multitude of advancements has been developed during this period, as the topic of concentrated solar power is becoming more mainstream. Improvements have been made in reflector and collector design and materials, heat absorption and transport, power production and thermal storage. Many applications that can be integrated with CSP regimes to conserve (and sometimes produce) electricity have been suggested and implemented, keeping in mind the environmental benefits granted by limited fossil fuel usage.

Kaneko et. al [23]: investigated the addition of MO_x (M: di- or tri-valent transition metal ion) into cerium dioxide (CeO_2) enhanced the ability of $CeO_2$for the oxygen(O_2)-releasing reaction at lower temperature and swift hydrogen (H_2)-generation reaction. CeO2–MOx(M¼Mn, Fe, Ni, Cu) reactive ceramics having high melting points were synthesized with the combustion method from their nitrates for solar H_2 production. The prepared CeO_2–MO_x samples were solid solutions between CeO_2 and MO_x with the fluorite structure through the X-ray diffractometry measurement. Two-step water-splitting reactions with CeO_2–MO_x reactive ceramics proceeded at 1573–1773 K for the O_2 -releasing step and at 1273 K for the H_2 -generation step by irradiation of infrared image furnace as a solar simulator. The amounts of O_2 evolved in the O_2 -releasing reaction with CeO_2 –MO_x increased with an increase in the reaction temperature.

Kalogirou et. al [24]: presented survey of the various types of solar thermal collectors and applications. Initially, an analysis of the environmental problems related to the use of conventional sources of energy is presented and the benefits offered by renewable energy systems are outlined. A historical introduction into the uses of solar energy is attempted followed by a description of the various types of collectors including flat-plate, compound parabolic, evacuated tube, parabolic trough, Fresnel lens, parabolic dish and heliostat field collectors. This is followed by an optical, thermal and thermodynamic analysis of the collectors and a description of the methods used to evaluate their performance. Typical applications of the various types of collectors are presented in order to show to the reader the extent of their applicability. These include solar water heating, which comprise thermosyphon, integrated collector storage, direct and indirect systems and air systems, space heating and cooling, which comprise, space heating and service hot water, air and water systems and heat pumps, refrigeration, industrial process heat, which comprise air and water systems and steam generation systems, desalination, thermal power systems, which comprise the parabolic trough, power tower and dish systems, solar furnaces, and chemistry applications. As can be seen solar energy systems can be used for a wide range of applications and provide significant benefits, therefore, they should be used whenever possible.

2.2 RESEARCH GAP

Most of the researches in concentrated solar heat applications are carried out in Europe and North America. With the collaboration of UNDP, MNRE has also taken up some applications of CST in textile, paper and pulp, automobile, food processing and dairy, desalination, hospitality and many other heat processing industries. There is strong demand of heat energy in hospitality sector. On an average 60% of energy is spending as heat energy in hospitality sector. If we can switch over to CST, a lot of conventional energy can be saved. The present study is an attempt to analyse solar thermal technology for steam generation to be used for laundry, in kitchen and for bathing purpose. Based on above thought the following objectives are identified.

2.3 OBJECTIVES OF THE PRESENT WORK

Aim of this thesis is to develop hospitality industry which is sustainable and environmental friendly by reducing the use of fossil fuels and maximizing the use of solar energy to fulfil thermal needs of the industry. Following objectives need to be achieved for successful design of solar concentrator based mechanical process heat applications in hospitality industry:-

- To study the various heating processes involved in hospitality industry.
- To find out the temperature range at which thermal energy is required in these processes in what form.
- To design the feasible concentrated solar heat (CSH) solution to fulfil thermal energy requirement in hospitality industry.
- To integrate designed solar industrial process heating system with existing steam generation and distribution system based on fossil fuels in hospitality industry.
- To estimate the generation potential of designed SIPH system at selected hospitality.

- To estimate solar fraction achieved by SIPH system at selected hospitality industry.
- To calculate economic feasibility and payback period of the designed SIPH system.

CHAPTER 3: CONCENTRATED SOLAR POWER

Solar energy is inexhaustible source of energy with $1.8 * 10^{11}$ MW of power radiated by sun on earth [**26**]. This amount is thousand times larger than present consumption of mankind from all commercially available energy sources. Therefore solar energy can supply all our future energy needs on continuous basis. Two major benefits of solar energy as most promising renewable source of energy is that first it is environmental friendly clean source of energy and secondly it is freely available in large quantities in all part of world where people generally lives.

Solar energy is the cleanest, most abundant renewable energy source available. The India has some of the world's richest solar resources. There are three primary technologies by which solar energy is commonly harnessed: photovoltaic (PV), which directly convert light to electricity; concentrating solar power (CSP), which uses heat from the sun (thermal energy) to drive utility-scale and heating and cooling systems, which collect thermal energy to provide hot water and air conditioning.

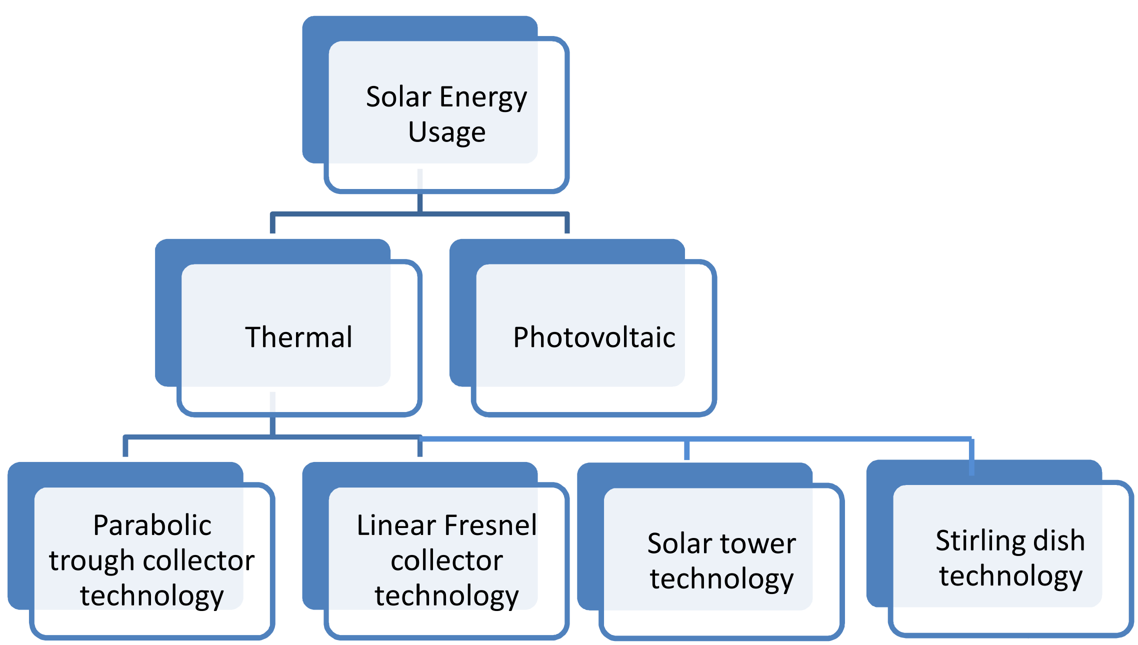

Figure10: - classification of methods of solar energy utilization (source: - internet)

3.1 SOLAR POWER RESOURCE IN INDIA

India receives sun shine over 300 days a year which is a significant portion of the year. About 5,000 trillion kWh per year energy is incident over India's land area. Theoretically, if captured effectively, a small fraction of the total incident solar energy, can meet the entire country's power requirements. Ministry of New and Renewable Energy (MNRE) has sanctioned National Institute of Wind Energy (NIWE) to set up the network of solar radiation resource assessment (SRRA) stations all over the country to estimate the availability of investor solar radiation which is crucial for implementation of solar power projects. Following figure gives an overview of solar radiation resource assessment station **[27]**: -

Figure11: - solar radiation resource assessment station (source: - NIWE)

A SRRA station consists of two towers of 1.5 m and 6 m tall for measuring solar data and meteorological parameters respectively. The 1.5 m tower houses Pyranometer to measure GHI, Pyranometer with shading disc to measure diffused radiation and Pyroheliometer to measure DNI. The 6 m tall tower houses sensors for measuring ambient temperature, relative humidity, atmospheric pressure, wind speed, wind direction, rain fall and data acquisition system. Each SRRA station is powered by solar panels.

3.1.1 DIRECT NORMAL IRRADIANCE (DNI)

Direct Normal Irradiance (DNI) is the measure of sun based radiation got per unit range by a surface that is constantly held normal to the beams that arrived in a straight line from the heading of the sun at its present position in the sky **[28]**. Mostly, you can augment the measure of irradiance every year gotten by a surface by keeping it normal to approaching radiation. This amount is specifically noteworthy to concentrating solar thermal installations and installation that records the position of the sun.

[29].

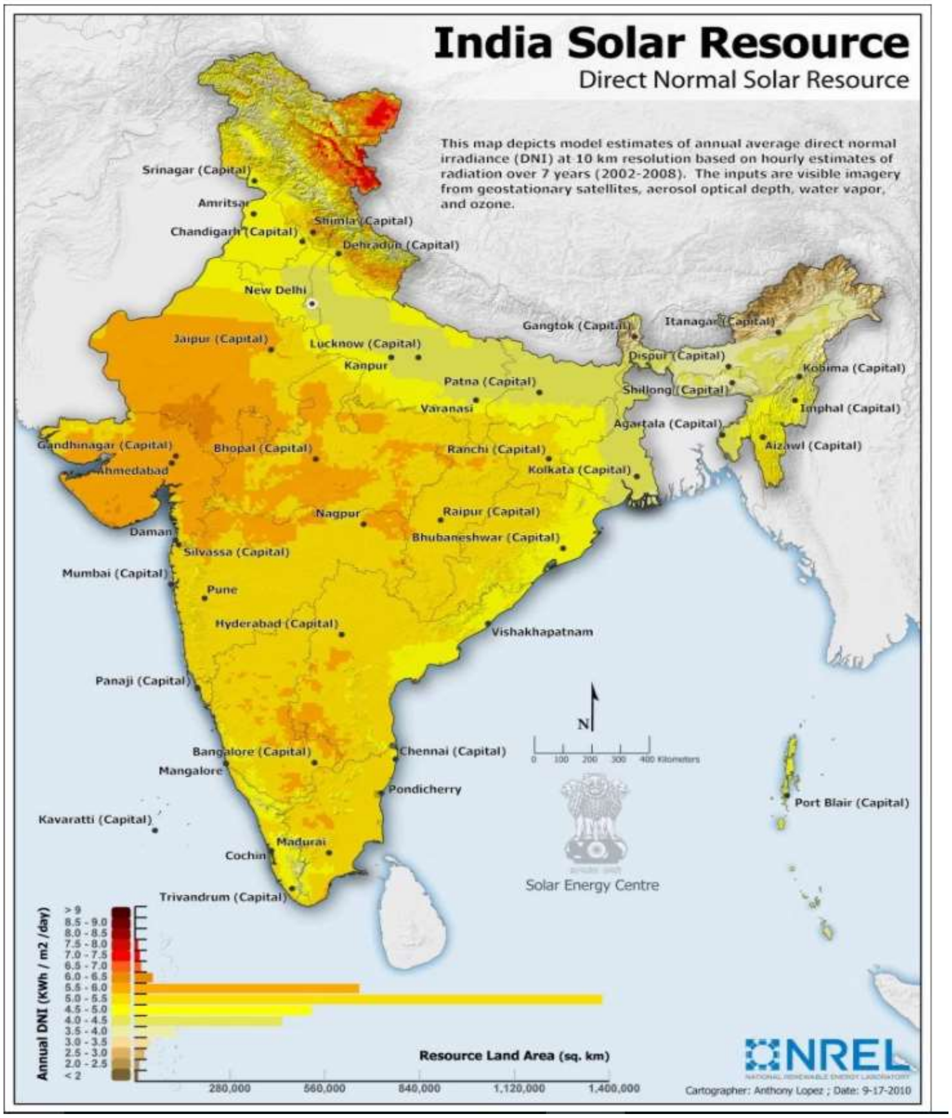

Figure12: - Direct Normal Irradiance Resource – annual average (source: - NISE)

3.1.2 GLOBAL HORIZONTAL IRRADIANCE (GHI)

The radiation coming to the earth's surface can be shown in various diverse ways. Global Horizontal Irradiance (GHI) is the aggregate sum of shortwave radiation trapped from above by a surface even to the ground. This esteem is specifically noteworthy to photovoltaic establishments and incorporates both Direct Normal Irradiance (DNI) and Diffuse Horizontal Irradiance (DIF) **[29]**.

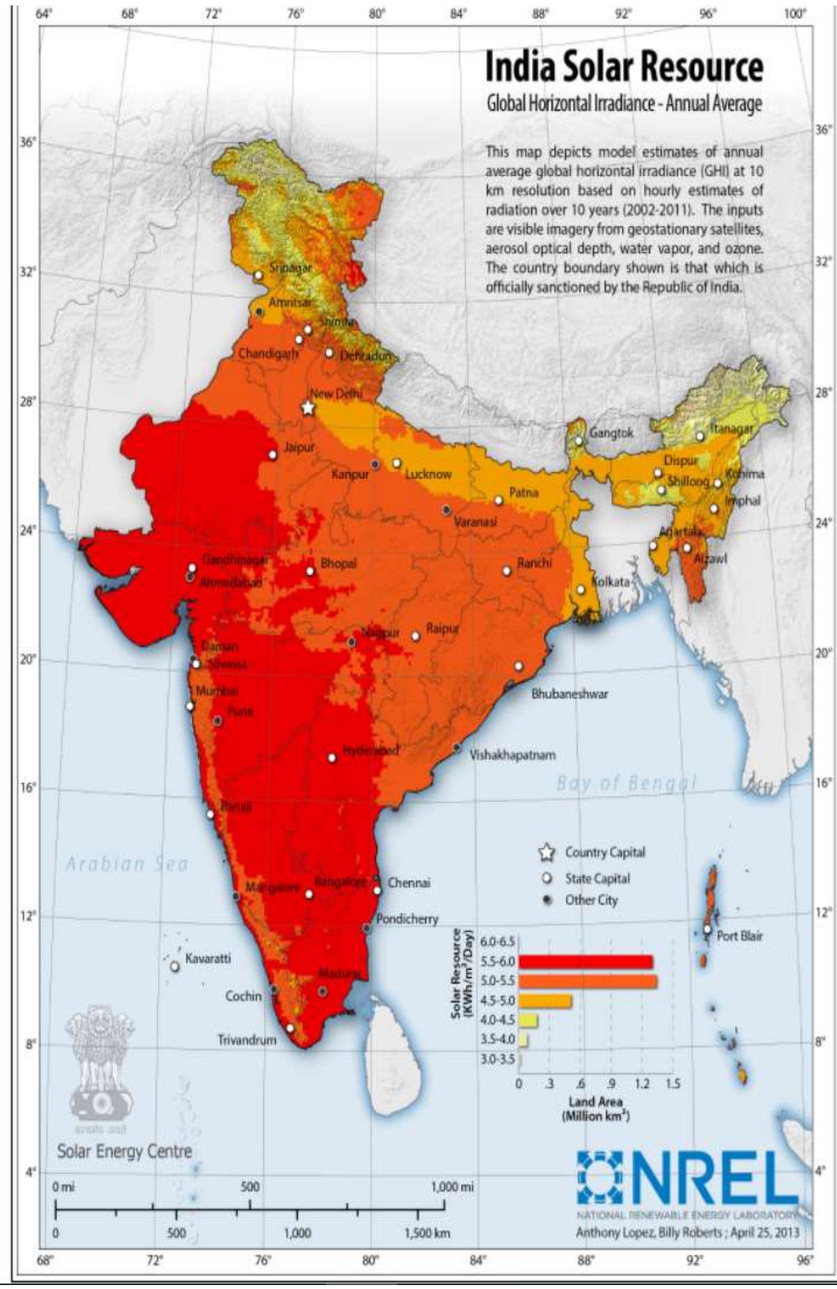

Figure13: - Global horizontal Irradiance Resource – annual average (source: - NISE)

3.2. BASIC PRINCIPLES OF SOLAR CONCENTRATION

Concentrated solar radiation is achieved by refracting lenses or reflecting mirrors and tracking systems which focuses a large area of sunlight into a small absorber which is surrounded by transparent covering. While using optical objects it also introduces certain losses like absorption losses in mirrors, reflection losses, and geometric imperfection losses. Combination of all these losses is termed as **optical efficiency**.

The dish which accordingly tracks the sun in the E-W heading from morning to night is single pivot followed framework. For the season variety in sun position in N-S heading, modifications must be made physically every couple of days by an administrator.

3.2.1 DEFINITIONS

A few parameters are utilized to determine concentrating collector as follows:-

- **Absorber area (A_{abs})**: - is the total area of the absorber surface that receives the concentrated radiation. It is likewise the zone from where helpful vitality can be acquired.
- **Aperture area (A_a): -** is the plane opening of concentrator through which the solar radiation is incident.
- **Acceptance angle (θ_a)**: - angular limit over which incident radiation deviate from normal to aperture plane and smoothly reached receiver. Therefore a collector with large acceptance angle values demands seasonal adjustments, whereas concentrator with acceptance angle small is needed to make continuous adjustments.
- **Geometrical Concentration ratio (C)**: - it is the ratio of aperture area and the absorber area.
- **Intercept factor (γ): -** it is the fraction of radiation reflected from concentrator and incident on absorber. Usually value of intercept factor is close to 1.

3.2.2 METHODS OF CLASSIFICATION

Concentrating collectors can be of reflecting mirrors type or refracting lens type. Reflecting surfaces can be flat shape, spherical or parabolic. This surface can be continuous or segmented profile. On the basis of image formation concentrator can be classified as non-imaging and imaging. Imaging types are farther classified as point or line.

Concentrators are also divided on the basis of temperature they achieve. If one needs high temperature then it is achieved by high concentration ratio and vice-versa. Concentrators are also designed on the basis of tracking of tracking of sun as single axis tracking or double axis tracking.

3.2.3 THERMAL ANALYSIS OF CONCENTRATING COLLECTORS

For a single axis tracking or for line focus collector the maximum possible concentration is given by the formula: -

$$C_{m,2D} = 1/\sin(\theta_a)$$

Where, θ_a, is the half acceptance angle limited by the size of the sun's disk and small scale errors.

For dual axis tracking point focus collector maximum possible concentration is given by this formula: -

$$C_{m,3D} = 1/\sin^2(\theta_a)$$

For a perfect collector and tracking system C_{max} depends only on the sun's disk which has a width of 0.53°(32′). Half angle subtended by sun at earth is 0.267°. Putting this value in the above formula for maximum possible concentration ratio for line focussing and point focusing is calculated as 216 and 46,747 respectively. But for practical systems, concentration ratio is always lower as acceptance angle is greater than 0.267°. Also tracking errors, imperfection in reflecting surface, mechanical misalignment between concentrator and receiver also lowers concentration ratio values. Energy balance on the absorber comes out with the following equations to be used for thermal analysis of concentrating collectors:-

$$\mathbf{Q_u = A_a * S - Q}$$

Where Q_u = useful heat gain rate

A_a = aperture effective area

S = solar beam radiation absorbed in absorber

Q_l = absorber heat loss rate

$$\mathbf{Q_l = U_l * A_p * (T_{pm} - T_a)}$$

Where U_l = overall heat loss coefficient

A_p = absorber surface area

T_{pm} = average temperature of absorber surface

T_a = ambient air temperature

$$\mathbf{Q_u = A_a * [S - U_l/C * (T_{pm}-T_a)]}$$

Where $C = (A_a/A_p)$ is concentration ratio

3.3. TYPES OF SOLAR THERMAL COLLECTOR

CST (Concentrated Solar Thermal) is a technique which can be used to concentrate the solar radiations with the help of mirrors or lenses to produce temperature in the range of 100 to 450°C and even more. For efficient performance, these devices required a tracking system so that the Sun rays can be focused onto the receiver all the time. They can tap only direct normal radiations and not the diffuse. CST systems are useful for medium to high temperature requirements in various industries, commercial establishments and institutions.

There are various techniques which can convert solar energy into thermal energy.

- Fixed Focus Elliptical Solar Dish (Scheffler)
- Fresnel Reflector Based Dish
- Linear Fresnel Reflector Concentrator
- Non-Imaging Concentrator
- Parabolic Trough Concentrator
- Paraboloid Dish

3.3.1. Fixed Focus Elliptical Solar Dish (Scheffler)

A Fixed Focus Elliptical Dish also called Scheffler Dish consist of large number of mirrors that can move to reflect the Sun's radiations onto a fixed receiver which contain a working fluid to be heated. Generally water is used as the working fluid but some other suitable fluid can also be used._The dish which automatically tracks the Sun in E-W direction from morning to evening is called Single-Axis tracking system. In Dual-Axis tracking system, the seasonal variation in the Sun position in N-S direction is also adjusted automatically which is needed to be adjusted manually in former **[30]**.

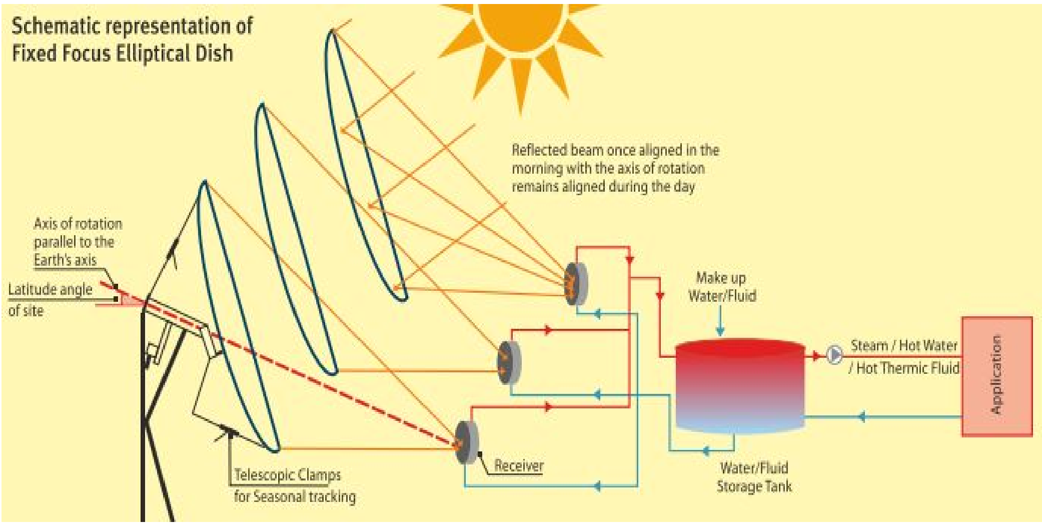

Figure14: - Fixed Focus Elliptical Dish - scheffler dish (source: - CSH)

Key Features

- Proven technology with a number of working installations for community cooking, air-conditioning and other applications.
- As its stationary system mounted on the ground, this system is structurally simple and has no rotating or flexible joint for water and steam.
- It can be installed on roof tops of existing buildings or on the ground.
- This system requires a skilled operator to obtain high efficiency and its efficiency decreases rapidly with increase in operating temperature.
- Scheffler dishes deliver heat only in late morning to early evening and are therefore suitable for operations that use heat during this period.
- Since dish and receiver has to be mounted separately, this system requires larger area as compared to other CST technologies.

3.3.2. Fresnel Reflector Based Dish

Fresnel reflector based dish (Fresnel Dish) is made up from panels of flat mirrors mounted on a frame such that the incident sunlight is reflected on to a cavity receiver which is specially designed to reduce heat losses. The receiver which is insulated on the outside is held in a fixed position in relation to the reflectors by means of a suitable structure so that the entire array and receiver moves together to track the Sun. Cavity receiver allows energy to intercepted through a small opening which result in low losses. Usually Fresnel Dishes are large and could have an aperture area of $100m^2$ or $160\ m^2$.

The reflector and the receiver are moved to track the Sun such that the reflector faces the Sun all the times throughout the year. These systems, because of their size, require careful structural design to withstand their heavy weight and stress that might be caused by strong winds. Fresnel Dishes have high efficiency throughout the year.

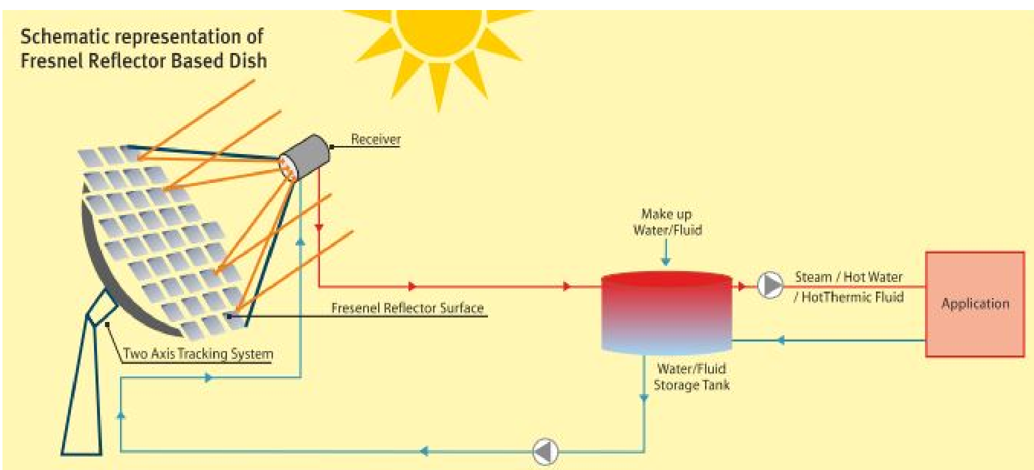

Figure15: - Fresnel Reflector Based Dish (source: - CSH)

Key Features

- Fresnel dish is a proven technology with number of working installations for process heating and other heating applications.
- Fresnel dish can be mounted on the roof top of an existing building though this requires considerable strengthening of the structure and must be designed by expert.
- High concentration ratio and relatively low losses from the receiver.
- Steam can be generated up to 25 bar.

3.3.3. Linear Fresnel Reflector Concentrator (LFRC)

LFRC are made from strips of straight reflecting material which could be highly polished reflecting metal or metal coating with reflecting material such as glass mirrors or metalized plastic which can withstand sunlight as well as rain. The surface reflects the incident sun radiations onto a metallic pipe (receiver) that runs above the array of reflectors. The pipe is coated to increase the absorption of the sunlight that falls on them and encased into a glass casing to minimize the convective losses. To increase the efficiency the glass casing may be evacuated and the ends may be sealed. The reflector strips are moved such that they always reflect the sunlight onto the receiver tube.

Several such LFRC's can be connected in series on a common axis. The two common methods of mounting are:

1. Horizontal E-W direction - reflectors are set in a continuous array so that the incident sunlight has the minimum angle of incidence.
2. Horizontal N-S direction – trough are set to track the sun from east to west from morning to evening. These systems require a large contiguous area and can provide large quantities of heat. They have efficiency similar to PTCs but have advantage of more robust structure.

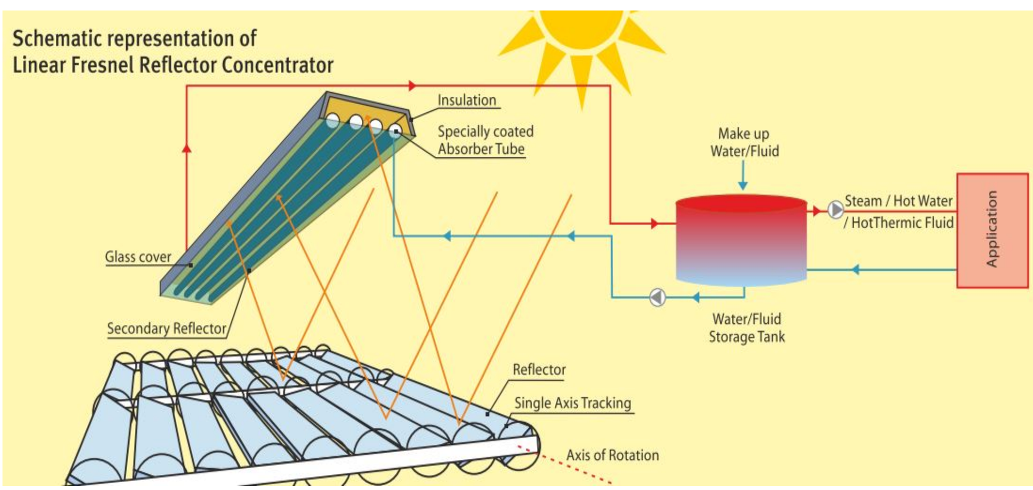

Figure16: - Linear Fresnel Reflector Concentrator (source: - CSH)

Key Features

- LFRC technology has installed plants for water desalination and power generation.
- Due to long reflectors they should be structurally strong and well supported otherwise their efficiency may suffer.
- LFRCs do not have any leakage problem due to absence of any flexible joint for water and steam.
- Due to medium concentration ratio and losses its operating temperature is limited up to 250°C.
- Large space is required for its installation as compared to other CST technologies.

3.3.4. Non-Imaging Concentrator (NIC)

It is also called Compound Parabolic Collectors (CPC). It consists of specially coated absorber tube which is enclosed in a concentric glass tube to reduce the convection losses. The space between the tube and its cover is evacuated. The tube is placed at the focal length of two parabolic reflectors. The axes of two parabolas are inclined at the acceptance angle which is the angle by which direct light may deviate from the normal and yet allow the reflected light to reach the receiver.

Usually these concentrators are 1m to 6m wide and can have up to $60m^2$ of collector area. The working fluid may be water or any other thermic fluid. The most common method of panel mounting is E-W direction with the panel facing in south direction, and inclined from ground at an angle of latitude + 10°.

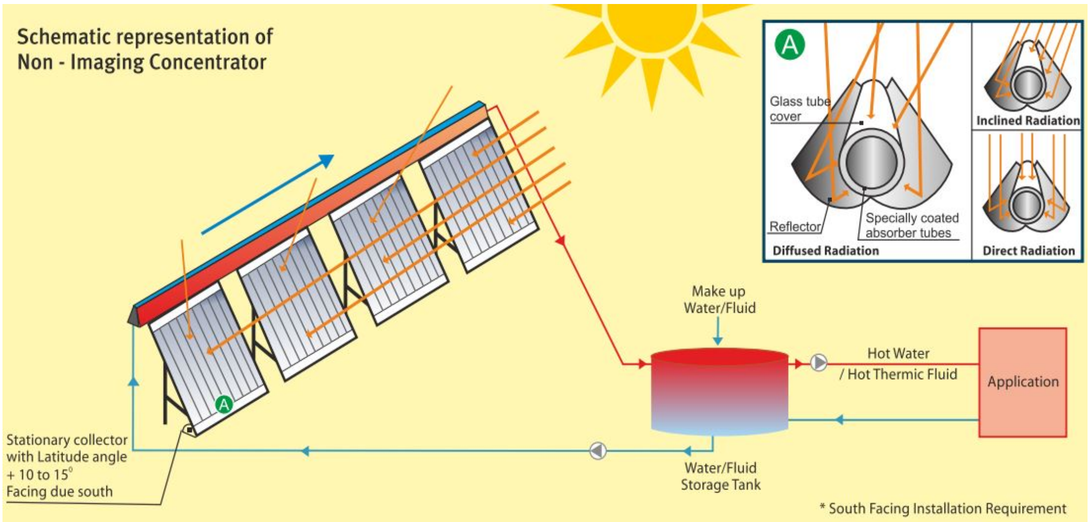

Figure17: - Non-Imaging Concentrator source: - (CSH)

Key Features

- There are no flexible or rotating joints for working fluid, so no problem of leakage.
- NICs can be installed on rooftop of existing structures.
- It has low concentration ratio and so operating temperature is limited to 120°C.

3.3.5. Parabolic Trough Concentrator (PTC)

PTCs are made from metallic sheet and coated with a reflecting material like highly polished metal (usually Aluminum) or metalized plastic so that it can withstand sunlight as well as rain. The metallic surface (trough) reflects the sunlight on to the receiver surface (metallic collector pipe) that runs axially along the trough. Like other systems receiver pipe is coated to increase the absorption of sunlight and encased into a glass tube to reduce the convective losses. Sometimes to increase the efficiency of the system the glass tube is evacuated and the ends are sealed. PTCs can be connected in series on a common axis.

Two common method of mounting PTCs are:

1. In a horizontal E-W direction in which trough are needed to adjust continuously to minimize the angle of incidence of sunlight.
2. In a horizontal N-S direction in which troughs are moved to track the sun from morning to evening from east to west. This mounting required a large contiguous area and generally used when large amount of heat is required.

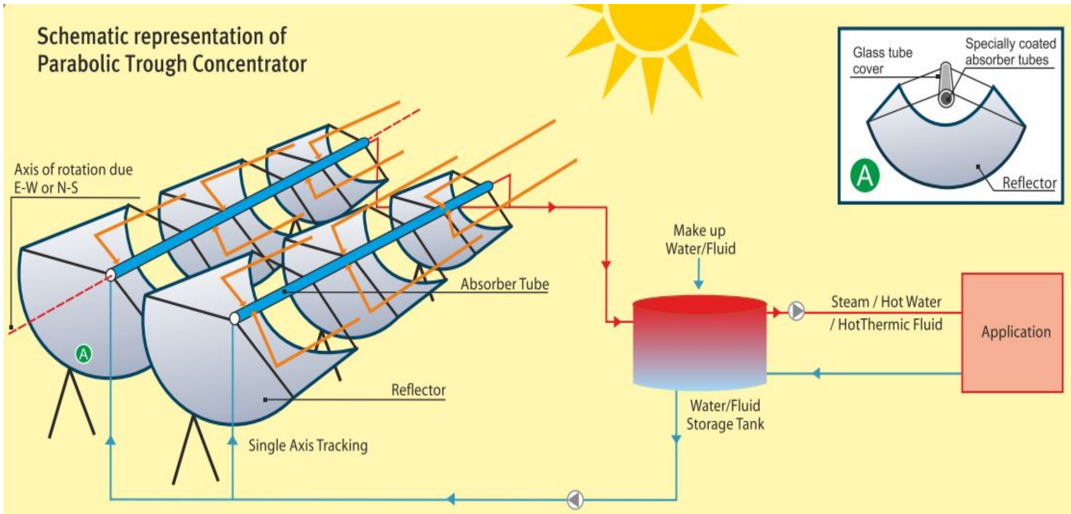

Figure18: - Parabolic Trough Concentrator (source: - CSH)

Key Features

- Currently PTCs have a number of working installations for process heating and power generation.
- Due to long structure, it should be strong enough to withstand distortion which may result of poor efficiency.
- PTCs have rotating and flexible joints for working fluid so these have to be maintain to prevent leakage.
- Its medium concentration ration and relatively high losses from the receiver limits its temperature to 250°C.

3.3.6. Paraboloid Dish

Paraboloid Dish made up from mirrors mounted on a truss in such a way that the incident sunlight reflected on to a cavity receiver which is designed to minimize convective and radiation losses. The receiver is fixed with respect to the reflectors by means of a suitable structure and so the entire structure moves together to track the Sun. the receiver is of cavity type which allows energy to intercept through a small opening to minimize the losses.

The entire structure moves in such a way that the reflector faces the Sun all the time throughout the year. Paraboloid dishes have high efficiency throughout the year.

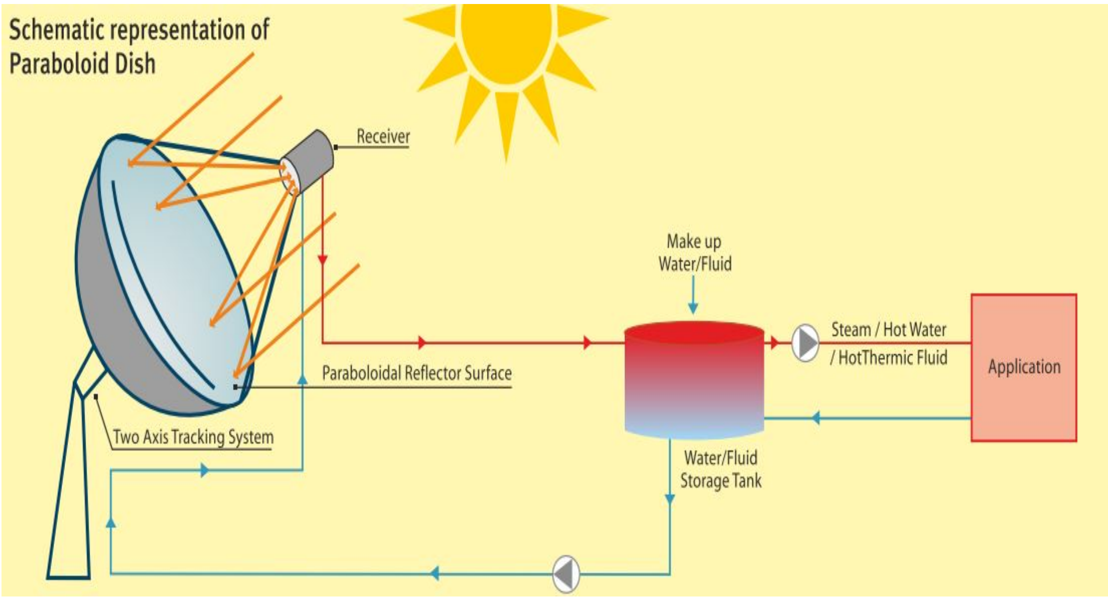

Figure19: - paraboloid dish (source: - CSH)

Key Features

- Paraboloid Dishes are pole mounted and thus required small area for installation.
- High concentration ration and low loss from the receiver allow its maximum temperature to reach up to 350°C.
- Paraboloid dish allow individual isolation and controls and hence can be mounted in a non-contiguous configuration.

3.4. SIPH CASE STUDIES IN INDIA

Two solar industrial process heat case studies have been discussed in detail here which shows the successful implementation of solar thermal technologies in industry for providing thermal energy for processes. Two case studies discussed are as follows:-

- Using scheffler dish for laundry applications.
- Using Arun dish for cooking process.

3.4.1 USING SCHEFFLER DISH FOR LAUNDRY APPLICATIONS

Scheffler dish based solar concentrators were installed at Purple creation Pvt Ltd., Pune for process heat applications. System consists of 30 scheffler dish of 16m^2 aperture area connected in series parallel arrangements at plant rooftop to provide pressurized hot water at 150^o C. LPG fired boiler is kept as a back up to SIPH system in case on non sunny days. Each scheffler dish has thermal output of 5.5 KW and 400 kg of weight. Single axis automatic tracking is used in collectors. Major details about the installation have been given in this table: -

Table6: - system details for SIPH case study at PCPL, Pune (source: - MNRE)

System details for PCPL,PUNE	
Aperture area of scheffler dish	11.56 m2
Number of dishes	30
Total aperture area	346.8 m2
Total shade free area required	30 * 35 = 1050 m2
Weight of dish	400
Total weight of system	30 * 400 = 12000 kg
Tracking	Single axis tracking
Heat delivery	30000 Kcal/day
Cost of LPG fuel replaced	Rs 20/- day
Per day fuel savings	4500 kg
Days of system operation	290
Total system cost	Rs 65,00,000
MNRE subsidy @ Rs 18000/- m2	Rs 16,80,000

Project cost for	Rs 48,20,000
Payback period	3.3 years

Therefore this project resulted in payback period of 3.3 years and 4500 kg of daily LPG savings due to SIPH system installed at the location. Also Arun dish shall reduce the carbon foot print. System would run the plant at minimal operation cost for the entire project life of 25 years.

3.4.2 USING ARUN DISH FOR COOKING PROCESS

Ramakrishna Mission Students Home, Chennai installed one ARUN dish to generate steam for cooking purpose. The ARUN dish is a two axis tracked dish installed on a column of 3m * 3m and on 8m height column. The area below the dish delivers steam at 170^{o} C for 7 hours daily which is used in cooking process of the kitchen. The dish is Fresnel paraboloid solar concentrator with a point focus. The automatic two axis tracking system ensures the highest thermal energy output per square of the collector is coupled with minimum maintenance over an extended period of time. Arun dish however can deliver steam at 25 bar pressure at 25 bar pressure at a temperature of 350^{o} C. Each module of Arun dish (104 m^2 aperture area and a weight of 12 tonnes) has an output capacity of up to 70 kW_{th}. Major details about the installation have been given in this table [**31**]: -

Table7: - system details for SIPH case study at RMSH, Chennai (source: - MNRE)

System details for RMSH, Chennai	
Aperture area of Arun dish	104 m2
Number of dishes	1
Total aperture area	104 m^2

Total shade free area required	120 * 1 = 120 m^2
Weight of Arun dish	20 tonnes
Total weight of system	1 * 12 = 12 tonnes
Tracking	dual axis tracking
Heat delivery	35,00,000 Kcal/day (peak delivery)
Cost of LPG fuel replaced	Rs 20/- day
Per day fuel savings	40 kg
Days of system operation	290
Total system cost	Rs 22,00,000
MNRE subsidy @ Rs 6000/- m2	Rs 6,24,000
Project cost for	Rs 15,76,000
Payback period	2.8 years

Therefore the project had a payback period of 2.8 years and 40 kg of daily LPG savings due to SIPH system installed at the location. Also Arun dish shall reduce the carbon foot print. System would run the plant at minimal operation cost for the entire project life of 25 years. Thus it makes a successful case study for other industries to go for solar thermal systems for industrial process heat needs.

3.5. HEAT STORAGE AND ITS APPLICATIONS

Major problem associated with solar energy utilization is its variable nature. Hence to overcome this variability, most of the SIPH system requires some sort of thermal energy storage. This storage system stores energy when it is in excess than requirement and energy can be made available for application use when solar energy is absent. Thermal energy can be stored as:-

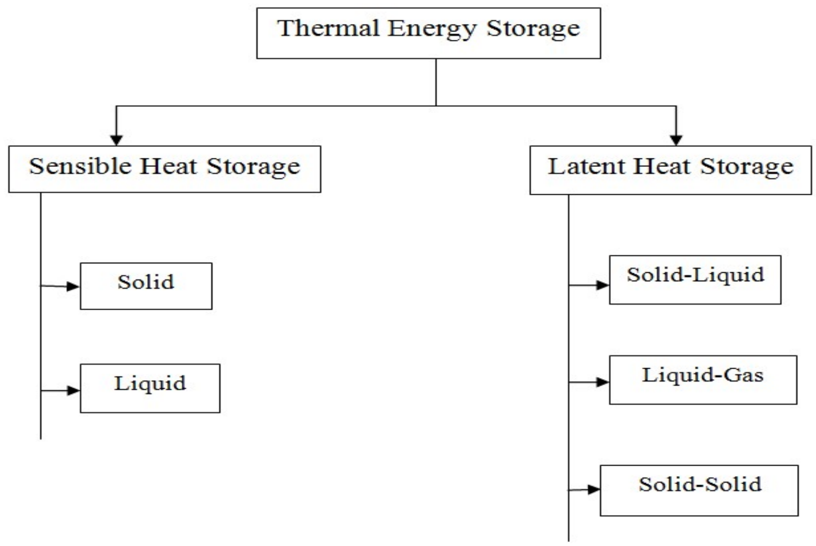

Figure20: - classification of thermal energy storage

Need of thermal energy storage in SIPH system can be justified from the following figure which shows that thermal load profile for a given industrial process remains constant for whole day but solar energy is available only during day time.

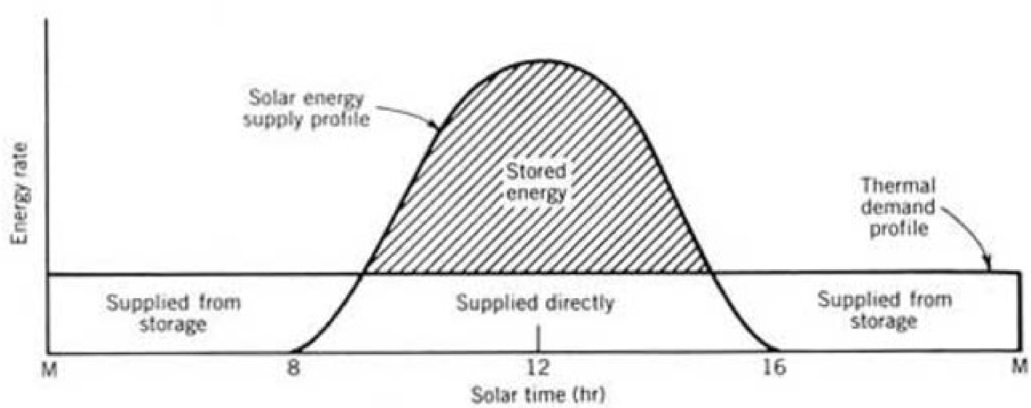

Figure21: - need for solar thermal energy storage (source: - powerfromthesun.net)

Also solar energy is available in excess to thermal energy load during daytime. This excess energy can be stored in form of sensible or latent heat which can be used to supply thermal energy during night time. Hence thermal energy storage can increase the share of solar energy in thermal load i.e. high solar fraction can be achieved due to storage and higher fuels savings can also be achieved.

3.6. RECENT POLICIES OF MNRE ON CST

Ministry of New and Renewable Energy (MNRE) is the nodal ministry in the government of India for all matters relating to renewable energy. The main objective of the ministry is to develop and implement renewable energy to supplementing the energy requirements of the India. The missions of ministry are as follows: -

- Energy security
- Increase in the share of clean power
- Energy availability and access
- Energy affordable
- Energy equity

3.6.1. CONCENTRATED SOLAR POWER INSTALLATION COST

Investment required for various CST depends upon various factors such as new project is being developed or CST is being retrofitted in existing system as new system can cost 15 to 30% higher due to additional costs of boilers and its other accessories like water treatment, piping, insulation etc. Also high altitude area with difficult terrain, cost may be further up by 20 to 25%. 5% of total cost is taken for setting up various CST: -

Table8: - installation cost of various CST for retrofitted system (source: - MNRE)

Technology	**Installation cost Rs per sq m in plains (approx)**
Fixed receiver elliptical dish (single axis tracked)	16000

Fixed receiver elliptical dish (dual axis tracked)	18000
Parabolic trough collector (PTC) with non evacuated heat receiver	16000
Parabolic trough collector (PTC) with evacuated heat receiver	18000
Linear Fresnel reflector (LFR) single axis tracked	18000
Arun dish (dual axis tracked)	20000
Paraboloid dish (dual axis tracked)	20000

3.6.2 CONCENTRATED SOLAR POWER SUBSIDY PATTERN

Ministry of New and Renewable Energy (MNRE) provide subsidy up to 30% of project investment to promote CST in India. Capital subsidy is provided on the basis of concentrated solar technology employed for process heat in Rs per sq m of collector installed to make payback periods lucrative. Besides subsidy, soft loan of 5% interest rate is provided by Indian Renewable Energy Development Authority (IREDA) for balance cost of system after deducting subsidy. For special category states like Himalayan region, islands and North east India, subsidy is up to 60%. For special case of non electrified villages of India subsidy for solar thermal system is up to 60%. Following table gives the overview of subsidy pattern available for setting up various CST: -

Table9: - subsidy pattern for various CST for retrofitted system (source: - MNRE)

Technology	Capital subsidy (Rs per sq m of collector area) or 30% of project cost whichever is less
Evacuated tube collector (ETCs)	3000
Flat plate collector (FPS) with liquid as the working fluid	3300
Flat plate collector (FPS) with air as the working fluid	2400
Solar collector system for direct heating applications	3600
Concentrated with manual tracking	2100
Non imaging concentrator	3600
Concentrator with single axis tracking	5400
Concentrator with dual axis tracking	6000

CHAPTER 4: DESIGN OF PARABOLOID DISH SOLAR COLLECTOR

Heat from sun’s rays can be harnessed to provide heat to a variety of applications such as cooking, cooling, industrial process heating, desalination and generating electricity. But in general, Sun’s rays are too diffuse to be of direct use in these applications. So solar concentrators are used to collect and concentrate sun’s rays to heat up a working fluid to the required temperature that make Sun’s heat suitable for these applications.

4.1. PARABOLOID DISH SOLAR COLLECTOR

Parabolic dish collector concentrates solar energy at a single focal point. The shape of a parabola means that incoming light rays which are parallel to the dish's axis will be reflected toward the focus, no matter where on the dish they arrive. Light from the sun arrives at the earth's surface almost completely parallel. So the dish is aligned with its axis pointing at the sun, allowing almost all incoming radiation to be reflected towards the focal point of the dish. Most losses in such collectors are due to imperfections in the parabolic shape and imperfect reflection. Following figure shows the major components of solar paraboloid dish **[32]**:-

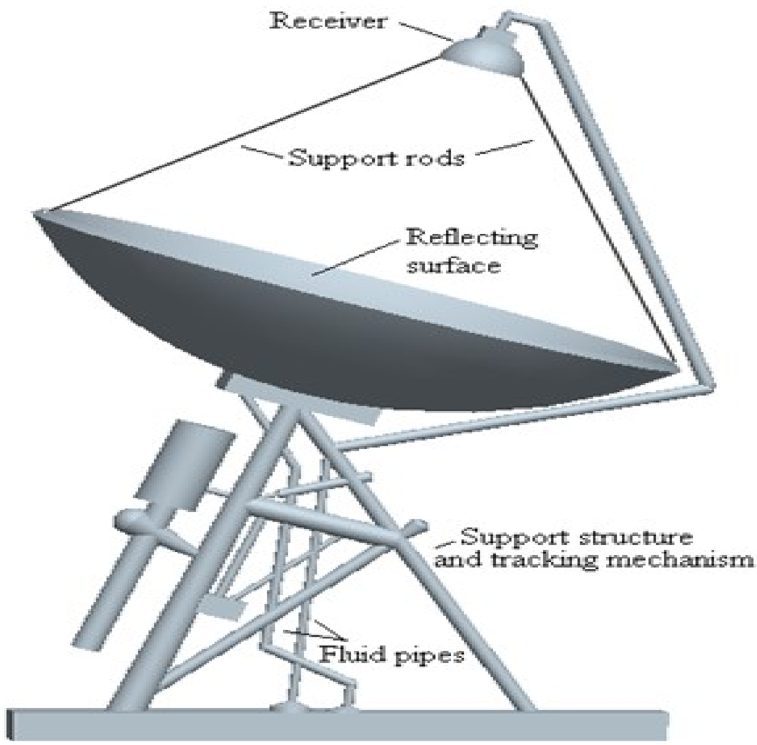

Figure22: - Parabolic dish solar collector components (source: - NREL)

Solar paraboloid dish comprises of following components with each subsystem having well defined function as follows:-

Collector: - collector is essentially made up of reflective mirrors which concentrate Sun's light at a fixed point focus. Thus high concentration ratio due to large collector aperture area of 14 m diameter and small receiver aperture area of 1 m diameter can be achieved up to 600 to 1000. Collector surface area is covered with highly reflective solar grade mirrors which reflect sunlight on to receiver with high optical efficiency of around 80%. Collector is supported by the space frame structure built of aluminium or MS tubes mounted on a long MS pedestal and supported by concrete foundation at the ground. Following figure gives the reflecting concentrator surface as follows:-

Figure23: - collector of solar paraboloid dish (source: - NREL)

Receiver: - Receiver placed of the focus of the dish, to absorb and transmit concentrated heat to continuously flowing working fluid like water or heat transfer oil continuously in helical tubes. Receiver is generally of inverted cavity type made of MS material. Following figure gives the receiver mounted on a support structure of dish as follows:-

Figure24: - cavity receiver of solar paraboloid dish (source: - NREL)

Tracking system: - In solar paraboloid Dish, collector concentrate sunlight on receiver tube forming a point focus. With sun's movement from east to west (diurnal) and north to south (seasonal), the collector continuously tracks about two axes, tracking sun's radiation and maintaining the focus of collector on receiver. East-west tracking is known as azimuth tracking and north-south tracking i.e. elevation tracking. Tracking can be of two types:-

- **Chronological Tracking**: - In this type of tracking system tracker motor moves the dish at preset time intervals according to azimuth-elevation position of sun for that latitude and longitude which are already fed to micro controller.

- **Light Sensing Tracking**: - in this type of tracking, tracker has Light sensors to track direction of sunlight and give feedback signal to microcontroller and microcontroller gives command to tracker motor to move the dish with sun by following it.

Following figure gives the working of dual axis tracking system mounted on a support structure of dish as follows **[33]**:-

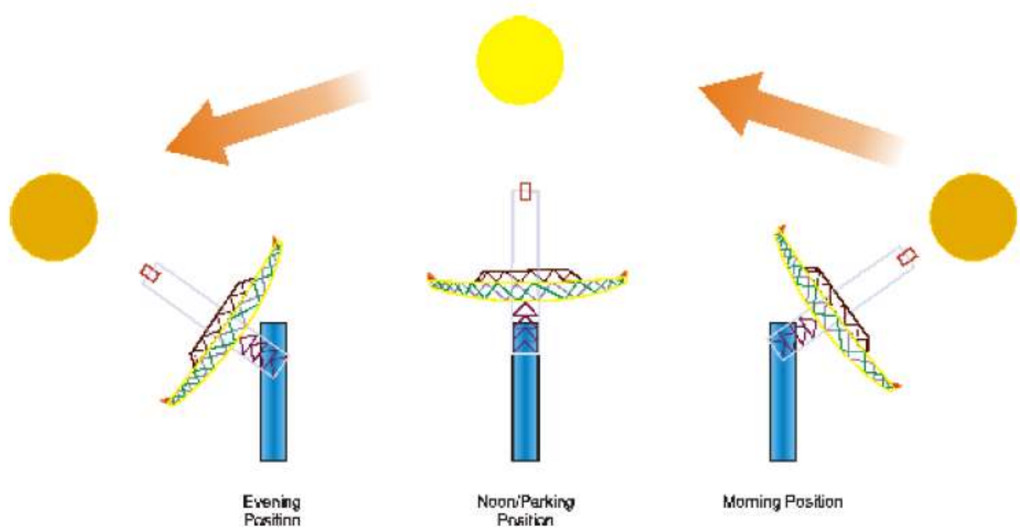

Figure25: - Azimuth –elevation (Az-El) type tracking for solar paraboloid dish

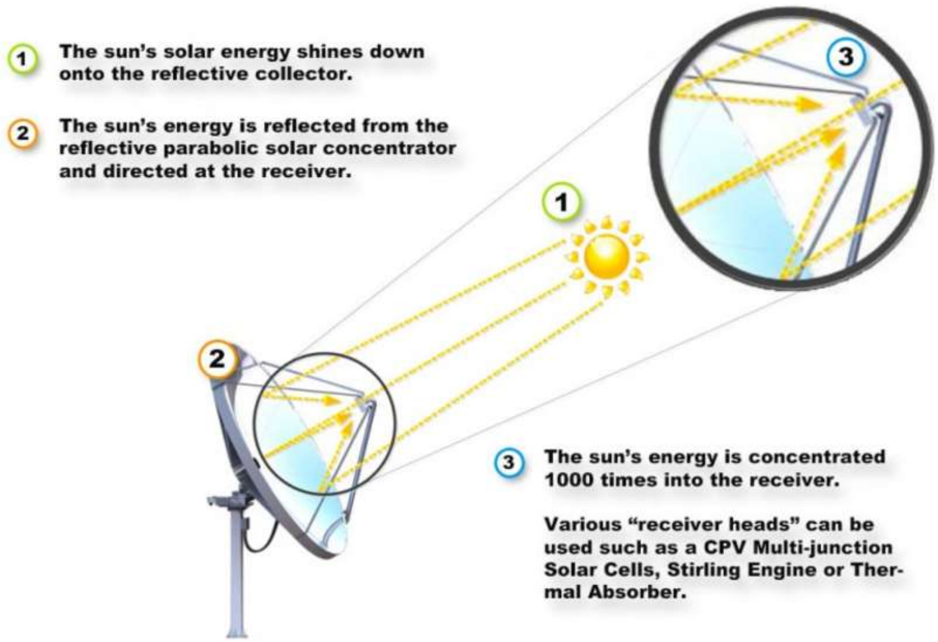

Figure26: - working of tracking device

Circulation system: - The circulation subsystem carries fluid and transfers the heat received by it to the end use application. Fluid circulates in the system at a certain desired rate to quickly and efficiently transfer the received heat from solar field to end use application. Circulation subsystem has a number of components such as pipes, pumps and valves to control fluid flow and temperature control sensors, etc.

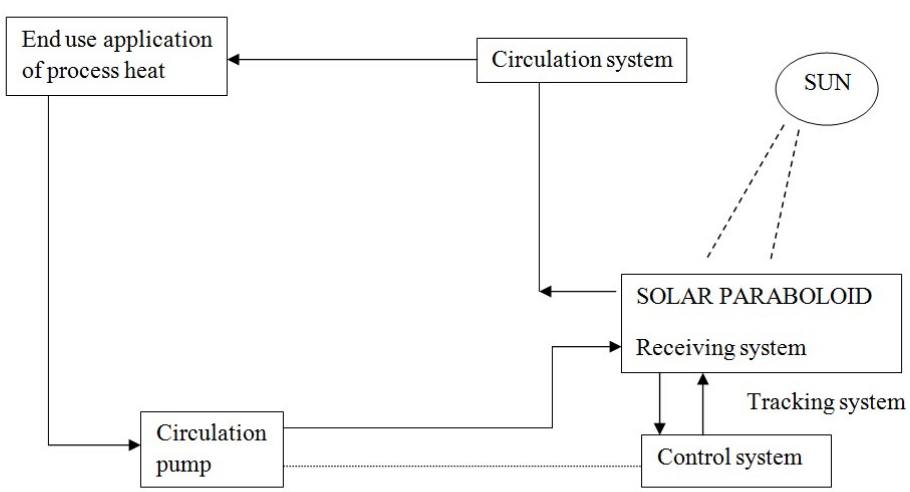

Figure27: - circulation and control system for solar paraboloid dish (source:-NISE)

Control mechanism: - Control Mechanism is the brain behind tracking system and circulation system. Microcontroller sends signals to the systems to control the tracking of the receiver based on pressure and temperature of the circulating fluid for end use application.

4.2. ENERGY BALANCE EQUATIONS

Fundamental solar collection equation is used to calculate the amount of heat going into the receiver. Amount of solar radiation entering the receiver depends upon solar source availability i.e. Direct Normal irradiance values (DNI) of site, size of concentrator i.e. Diameter and reflective surface i.e. reflectivity. Thermal efficiency depends upon receiver design and heat losses due to conduction, convection and radiation. Following equation gives the basic design energy balance equation **[34]**:-

$$Q_{useful} = I_{b,n} * A_{app} * E * (\cos\theta_i) * \alpha * \tau * \rho * \Phi - A_{rec} [U * (T_{rec} - T_{amb}) + \sigma * F * (T_{rec}^4 - T_{amb}^4)]$$

Where

Q_{useful} = instantaneous rate of thermal energy coming from receiver useful heat

A_{app} = area of concentrator aperture

A_{rec} = area of receiver aperture

E = fraction of concentrator aperture area not shaded by receiver, struts and so on

F = equivalent radiative conductance

$I_{b,n}$ = beam normal solar radiation (insolation)

T_{amb} = ambient temperature

T_{rec} = receiver operating temperature

U = convection conduction heat loss coefficient for air currents within receiver cavity and conduction through receiver walls

α = receiver absorptance

τ = transmittance of anything between reflector and absorber

θ_i = angle of incidence (angle between sun's rays and the line perpendicular to the Concentrator aperture)

ρ = concentrator surface reflectance

σ = Stefan Boltzmann radiant energy transfer constant

Φ = capture fraction or intercept (fraction of energy leaving the reflector that enters the receiver)

4.3. DESIGN OF DISH CONCENTRATOR AND RECEIVER

The function of the concentrator is to intercept solar radiation with a large opening i.e. aperture and reflect it on to a smaller area. The parameters associated with the design of the concentrator are as follows: -

- Concentrator aperture area, $\mathbf{A_{app}}$
- Receiver aperture area, $\mathbf{A_{rec}}$
- Un shaded concentrator aperture area fraction, **E**
- Angle of incidence, $\boldsymbol{\theta_i}$
- Surface reflectance, $\boldsymbol{\rho}$
- Capture fraction, $\boldsymbol{\Phi}$

4.3.1 CONCENTRATOR DESIGN

Paraboloid concentrator is a surface generated by rotating a parabola about its axis. Resulting shape directs all the parallel sunrays on to single point on its axis called focal point. Paraboloid dish is governed by the equation in x, y, z coordinate system as follows:-

$$X^2 + Y^2 = 4fz$$

Where

X = coordinate in aperture plane

Y = coordinate in aperture plane

Z = distance from the vertex parallel to symmetry of paraboloid

F = focal length

Focal length to diameter ratio **f/d** defines the shape of the paraboloid and relative location of focus. The shape is also described by rim angle **Ψm** which is angle measured at focus from the axis to the rim where paraboloid is truncated .The relationship between **f/d** ratio and rim angle is given as follows **[35]**:-

$$\mathbf{f/d = 1/4 * \tan(\Psi_m /2)}$$

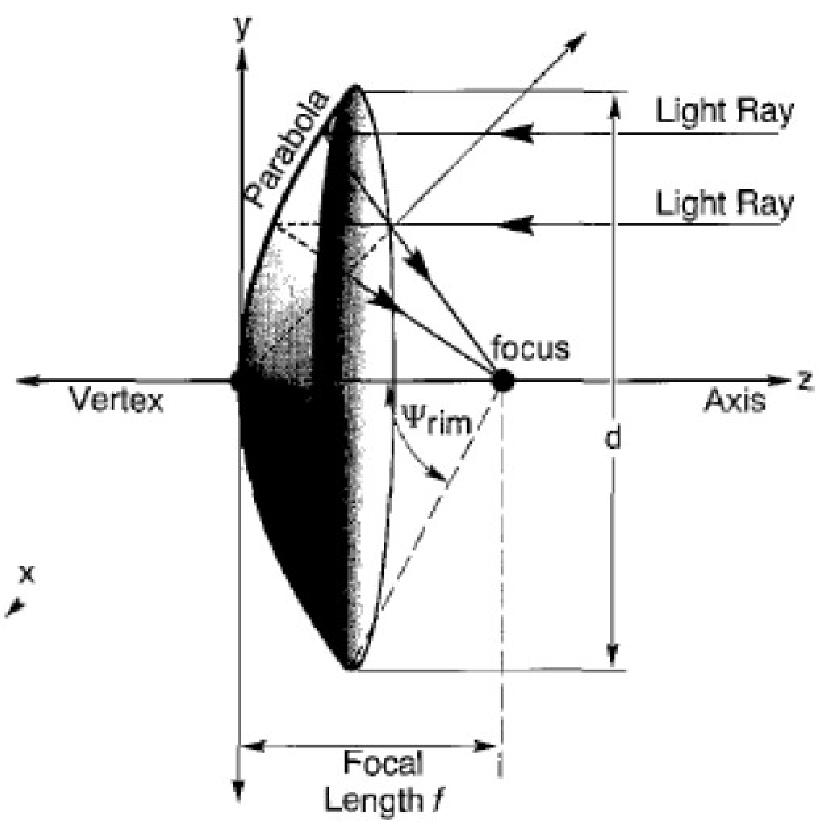

Figure28: - paraboloid dish with focal length, rim angle, diameter

f/d = focal length to diameter ratio, defines the shape of paraboloid and relative location of focus

Ψ_m = rim angle, it is the angle measured at focus from the axis to the rim where paraboloid is truncated

Geometry of Arun dish is shown in following figures: -

Geometric concentration ratio is defined ratio between the aperture area of the receiver to the reduced relative to that of concentrator. Expression for concentration of geometry is given as follows:-

$$CR_g = A_{app} / A_{rec}$$

Concentrator or optical efficiency is first measure of performance of concentrator that how much insolation coming at the aperture collector passes over an aperture of fixed size located at the focus of the concentrator. This is given as follows: -

$$\eta_{conc} = E * (\cos\theta_i) * P * \Phi$$

4.3.2 RECEIVER DESIGN

Receiver absorbs concentrated solar flux and converts it to thermal energy. Design of receiver depends upon following parameters: -

- Transmittance, τ
- Absorptance, α
- Receiver aperture area, A_{rec}
- Convection- conduction heat loss coefficient, **U**
- Equivalent radiation conductance, **F**
- Receiver operating temperature, T_{rec}

Receiver performance is given by the term receiver thermal efficiency which is defined as useful thermal energy delivered to working fluid divided by solar energy entering receiver aperture. Receiver thermal efficiency is given by equation as follows: -

$$\eta_{rec} = \tau * \alpha - [U * (T_{rec} - T_{amb}) + \sigma * F * (T_{rec}^4 - T_{amb}^4)] / \eta_{conc} * CR_g * I_{b,n}$$

Receiver efficiency can be increased by increasing cover transmittance, surface absorptance, reducing operating temperature, reducing capacity of receiver cavity to lose heat by conduction, convection and radiation.

Solar to thermal conversion efficiency is important parameter which is determined by combining optical efficiency and receiver thermal efficiency. This equation is given as follows: -

$$\eta_{overall} = \eta_{rec} * \eta_{conc}$$

4.4. DESIGN CALCULATION AND PERFORMANCE ANALYSIS

Design calculations are done for solar paraboloid dish to be used for industrial process heating system by using the basic heat gain equation and equations used for Concentrator and receiver design as stated above. Basic input variable are selected and constants necessary for calculations are assumed from appropriate reference to calculate the daily performance of solar dish. Design performance parameters are calculated like useful heat gain rate (Q_{useful}), geometric concentration ratio (CR_g), concentrator optical efficiency (η_{rec}) and overall system efficiency ($\eta_{overall}$). Following tables gives the value of basic input parameters and design coefficient assumed for calculations of paraboloid dish: -

Table10: - design parameters for solar paraboloid dish

Design Parameters	Design Value
Rim Angle Ψ_m (^{0})	45
F/d ratio	0.58
Diameter of Paraboloid dish (m)	14

Focal length (m)	8.16
Reflectivity of solar grade mirrors **P**	0.92
Angle of incidence for two axis tracking θ_i(°)	0
Un shaded aperture area fraction **E**	0.92
Capture/ Intercept fraction **Φ**	0.9
Transmittance **τ**	0.9
Absorptance **α**	0.9
Overall heat transfer coefficient of air currents **U** (W/m^2K) at 8.3 m/sec maximum wind velocity at Delhi	31
Receiver operating temperature / Temperature for steam production T_{rec} (°C)	175
Receiver cavity opening diameter (m)	1
Equivalent radiative conductance **F** for selective coating on receiver surface	0.3
Beam solar radiation for rated design value $I_{b,n}$ (w/m^2)	1000
Ambient temperature T_{amb} (°C)	30
Stefan Boltzmann constant σ (W/m^2K^4)	$5.67 * 10^{-8}$

Following design parameters are now used for calculation for various performance parameters of 14 m diameter solar paraboloid dish. Overall heat transfer coefficient **U** for the selected Delhi site is calculated for the air current flowing through cavity receiver are calculated by given formula as follows :-

$$U = 10.45 - v + 10\ v^{1/2}$$

Where

V = wind velocity in m/sec

Different values of U are calculated for different V values for plant at Delhi with corresponding value for maximum wind velocity of 8.3 m/sec is calculated as 31 W/m^2 K. This value is chosen for maximum heat loss that is possible from cavity receiver i.e. solar paraboloid dish is designed for worst case. Following figure gives the values for U for different wind speeds:-

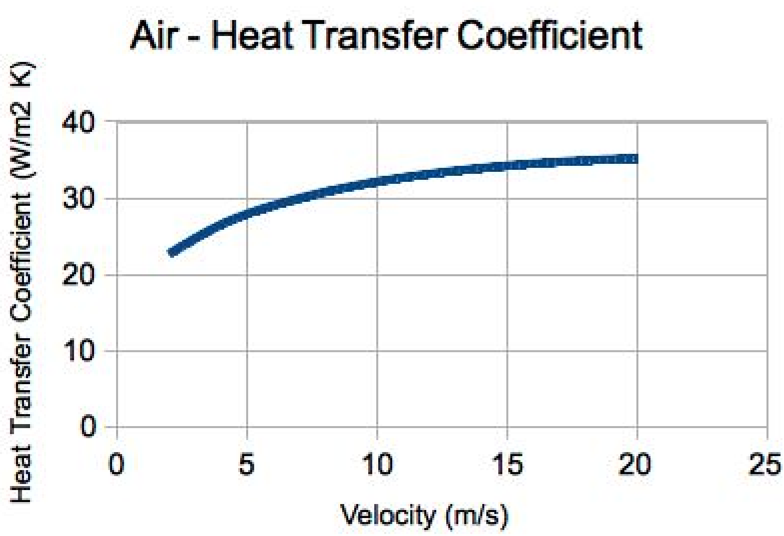

Figure29: - overall heat transfer coefficient VS wind speed curve

Following table gives the calculation procedure for estimating concentration optical efficiency, geometric concentration ratio, heat gain rate, heat loss rate, useful heat gain rate, receiver thermal efficiency and overall system efficiency as follows:-

Table11: - design calculation procedure for solar paraboloid dish

Diameter of paraboloid dish (m)	Optical efficiency	Receiver operating temp in Kelvin	Area of concentrating aperture m^2	Receiver diameter (m)	Receiver opening area (m)	Geometric concentration ratio	Solar radiation	Ambient temp (K)	Heat gain	Heat loss	Useful heat	Receiver efficiency	Overall system efficiency
14	0.761	448	153.86	1	0.75	205	1000	303	107588.14	4063.48	103524.66	0.781	0.614

14	0.761	448	153.86	1	0.75	205	950	303	102082.32	4063.48	98018.84	0.779	0.612
14	0.761	448	153.86	1	0.75	205	900	303	96585.28	4063.48	92521.8	0.777	0.609
14	0.761	448	153.86	1	075	205	850	303	91088.56	4063.48	87025.08	0.774	0.606
14	0.761	448	153.86	1	0.75	205	800	303	85576.19	4063.48	81512.71	0.771	0.603
14	0.761	448	153.86	1	0.75	205	750	303	80083.42	4063.48	76019.94	0.767	0.599
14	0.761	448	153.86	1	0.75	205	700	303	74579.13	4063.48	70515.65	0.763	0.595
14	0.761	448	153.86	1	0.75	205	650	303	69087.67	4063.48	65024.19	0.758	0.590
14	0.761	448	153.86	1	0.75	205	600	303	63571.91	4063.48	59508.43	0.751	0.584
14	0.761	448	153.86	1	0.75	205	550	303	58088.14	4063.48	54024.66	0.743	0.578
14	0.761	448	153.86	1	0.75	205	500	303	52583.92	4063.48	48520.44	0.731	0.571
14	0.761	448	153.86	1	0.75	205	450	303	47081.12	4063.48	43017.64	0.718	0.63
14	0.761	448	153.86	1	0.75	205	400	303	41588.39	4063.48	37524.91	0.705	0.555
14	0.761	448	153.86	1	0.75	205	350	303	36078.88	4063.48	32015.40	0.690	0.546
14	0.761	448	153.86	1	0.75	205	300	303	30592.02	4063.48	26528.54	0.682	0.536
14	0.761	448	153.86	1	0.75	205	250	303	25088.14	4063.48	21024.66	0.663	0.509
14	0.761	448	153.86	1	0.75	205	200	303	19576.37	4063.48	15512.89	0.621	0.457

14 m diameter solar paraboloid dish at 1000 W/m^2 will deliver useful heat gain rate of 103 KW at optical efficiency of 76.1%, receiver efficiency of 78.1% and overall system efficiency i.e. solar to heat conversion ratio of 61.4%. as DNI values decreases, all performance parameters start decreasing to 15 KW heat gain rate at 200 W/m2, 62.1% receiver efficiency and 45.7% overall system efficiency at 200 W/m2. However, optical efficiency remain constant with changing DNI values at 76.1% due to two axes tracking which keeps cosine losses always zero as it tracks the sun continuously for both sun's Azimuth and elevation positions. Geometric concentration ratio for 14 m concentrator diameter and 1 m receiver diameter is calculated as dividing concentration aperture area by receiver aperture area which gives the value of 205 i.e. radiation falling on receiver cavity gets intense by the factor 205 X. Following figure gives the variation for overall system efficiency and useful heat gain rate with DNI values as follows:-

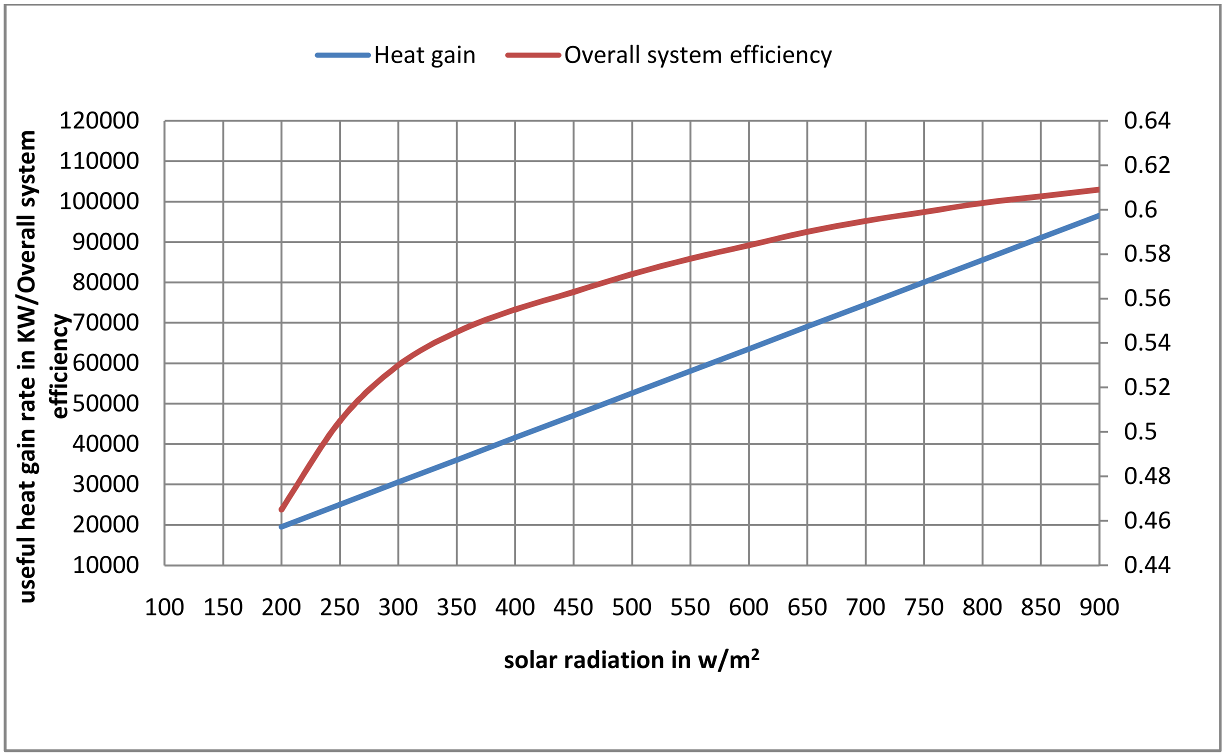

Figure30: - Overall system efficiency/ useful heat gain rate VS solar radiation curve

Overall system efficiency curve follows parabolic relationship with increasing solar radiation and reaches peak value of 61.4% for 1000 W/m2 and low value as possible for 200 W/m2 of 45.7%. On the other hand heat gain rate follows linear relationship with increasing solar radiation. Following figure gives the variation of receiver thermal efficiency vs solar radiation as follows: -

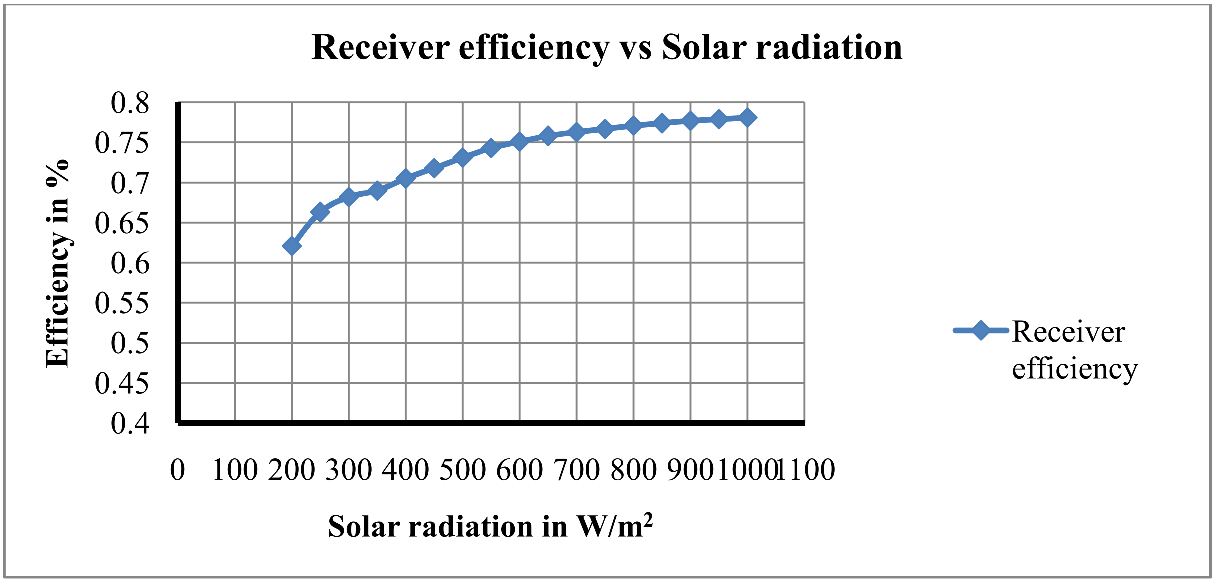

Figure31: - Receiver thermal efficiency VS solar radiation

Receiver thermal efficiency increases from 62.1% at 200 W/m2 to 78.1% at 1000 W/m2. Receiver thermal efficiency increases rapidly with increasing solar radiation but becomes almost constant at higher values of DNI. Now the daily performance of 14 m solar paraboloid dish was evaluated over the day with variation in DNI values form 6AM to 6PM on 28th April, 2017. The variation of DNI was recorded over the whole day at NISE weather station which recorded DNI VARYING from 42 W/m^2 to 907 W/m^2 at solar peak time. Following figure shows the variation of DNI at Delhi site for 28th April, 2017 as follows: -

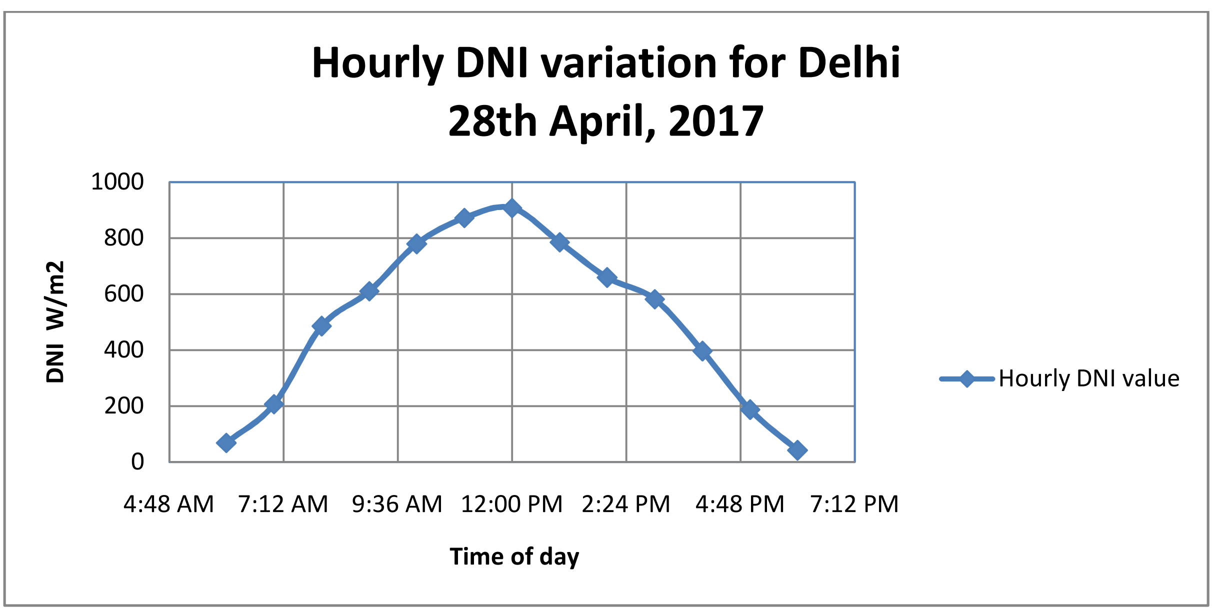

Figure32: - hourly DNI variation, Delhi source: - NISE weather station)

With varying DNI values recorded, important performance parameters i.e. optical efficiency, geometric concentration ratio, useful heat gain rate, thermal efficiency, and overall system efficiency were calculated on equation as stated above. Results showed in the table are complied in the form of curves showing the variation of each parameter calculated i.e. as variation of useful heat gain rate along with DNI. Useful heat gain rate varies from 1.1 KW at 69 W/m^2 in morning at 6AM to 93 KW at 12 PM when radiation is at 907 W/m^2 and then again drops to 1 KW for 42 W/m^2 radiations in 6 PM in evening. Hence the curve for hourly DNI variation and hourly useful heat gain rate variation are almost same in shape. Following table shows the calculation procedure followed to calculate above performance parameters for varying DNI over the whole days as follows:-

Table12: - design calculation procedure for daily performance analysis for solar dish

Rim angle	Dia of paraboloid dish (m)	Optical efficiency	Receiver operating temp (K)	Area of conc. Aperture (m^2)	Receiver dia (m)	Receiver opening area	Geometric concentration ratio	Time of day	Solar radiation	Ambient temp (K)	Heat gain	Heat loss	Useful heat	Receiver efficiency	Overall system efficiency
45	14	0.761	448	153.86	1	0.75	205	6:00 AM	69	303	5178.14	4063.48	1114.66	0.15	0.11
45	14	0.761	448	153.86	1	0.75	205	7:00 AM	207	303	20358.62	4063.48	16295.14	0.61	0.46
45	14	0.761	448	153.86	1	0.75	205	8:00 AM	485	303	50938.79	4063.48	46875.31	0.72	0.54
45	14	0.761	448	153.86	1	075	205	9:00 AM	610	303	64688.51	4063.48	60625.03	0.74	0.56
45	14	0.761	448	153.86	1	0.75	205	10:00 AM	779	303	83278.36	4063.48	79214.88	0.75	0.57
45	14	0.761	448	153.86	1	0.75	205	11:00 AM	872	303	93508.14	4063.48	89444.66	0.76	0.58
45	14	0.761	448	153.86	1	0.75	205	12:00 PM	907	303	97358.75	4063.48	93295.27	0.77	0.59
45	14	0.761	448	153.86	1	0.75	205	1:00 PM	785	303	83938.56	4063.48	79875.08	0.75	0.57
45	14	0.761	448	153.86	1	0.75	205	2:00 PM	659	303	70078.28	4063.48	66014.80	0.74	0.56
45	14	0.761	448	153.86	1	0.75	205	3:00 PM	582	303	61608.42	4063.48	57544.94	0.73	0.55
45	14	0.761	448	153.86	1	0.75	205	4:00 PM	396	303	41148.81	4063.48	37085.33	0.70	0.53

45	14	0.761	448	153.86	1	0.75	205	5:00 PM	187	303	18158.42	4063.48	14094.94	0.59	0.45
45	14	0.761	448	153.86	1	0.75	205	6:00 PM	42	303	5035.82	4063.48	972.34	0.13	0.10

Following result stated in above table is shown in figure for variation of useful heat gain rate throughout the day as follows:-

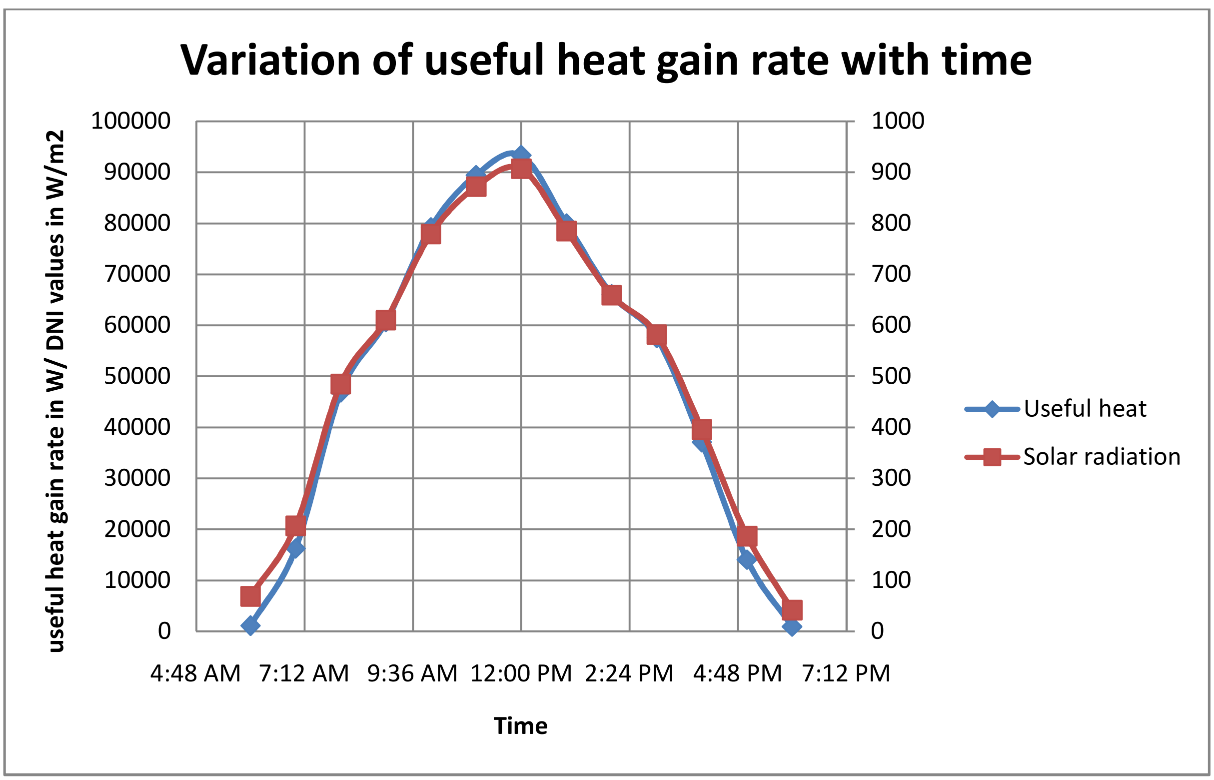

Figure33: - hourly useful heat gain rate variation for 28th Apr, 2017 at NISE

Now the variation of all three efficiencies i.e. concentration optical efficiency, receiver thermal efficiency and overall system efficiency with variation of DNI with time of the day is compiled. Optical efficiency remains constant throughout the day due to two axes tracking system, receiver efficiency starts increasing from morning reaches peak value at solar noon and again drops to minimum value in the evening, while overall system efficiency follows the same curve as receiver thermal efficiency. Following figure shows the variation of efficiency with time of day as follows: -

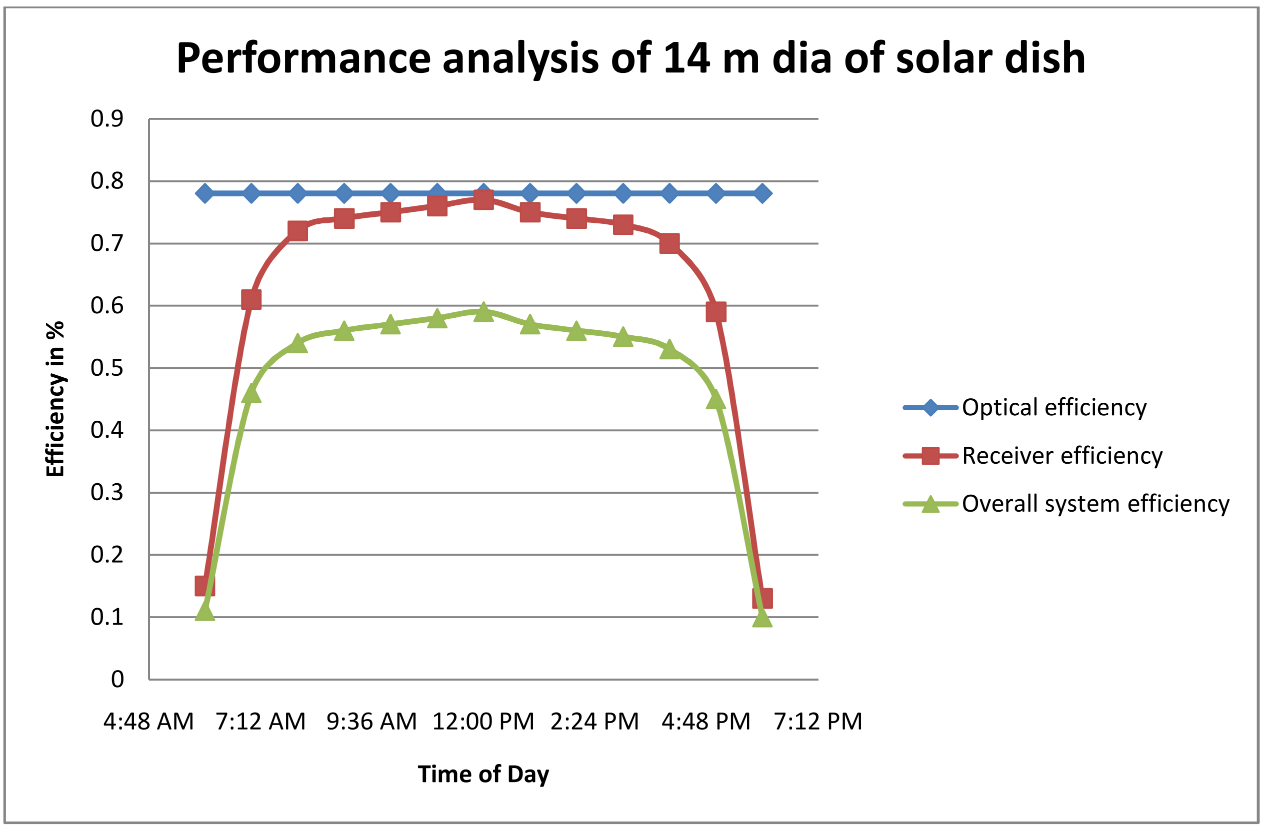

Figure34: - hourly efficiency variation for 28th Apr, 2017, Delhi

CHAPTER 5: INTEGRATION OF SIPH SYSTEM WITH HOSPITALITY INDUSTRY

5.1 PATTERN OF ENERGY CONSUMPTION IN HOSPITALITY INDUSTRY

The hospitality industry has a very high energy demand. According to a survey over 65% of the total energy demand is for heating and rest is for electricity. Hospitality industry has number of different heat processes mainly are laundry purpose, heat in kitchen and hot water for bathing. Various energy sources currently used in hospitality industry for heat generation are mainly natural gas with 59% in total energy consumption followed by electricity as second largest source with share of 39% and followed by others sources of energy with merely 2%. Following figure shows share of various energy sources in hospitality industry: -

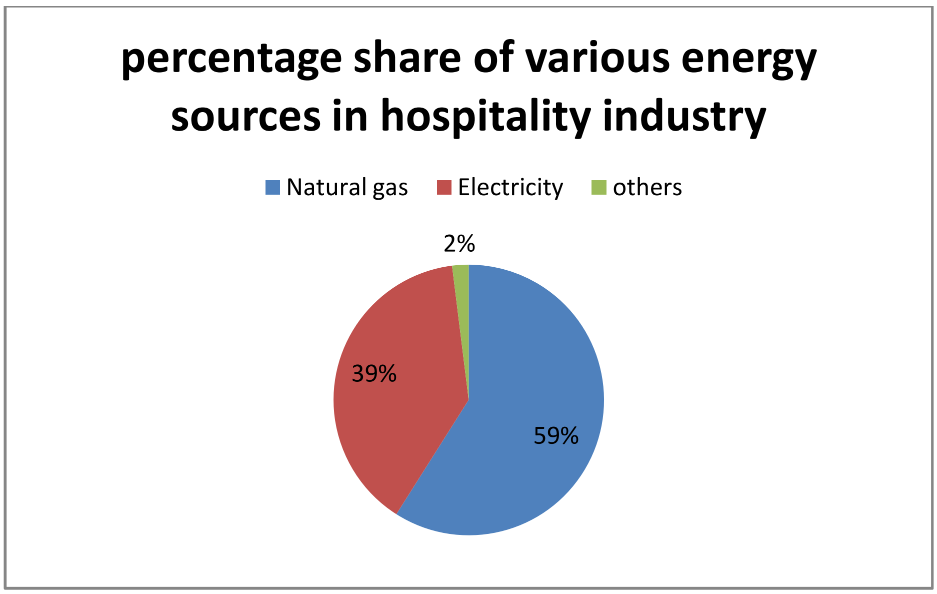

Figure35: - share of energy sources in hospitality industry

Total energy consumed from all the sources of energy can be grouped according to three different processes. Most of the energy consumed is in kitchen with share of 66% in total energy consumption, followed by 25% in laundry and 9% in bathing. Following figure gives the percentage share of total energy consumption in various processes: -

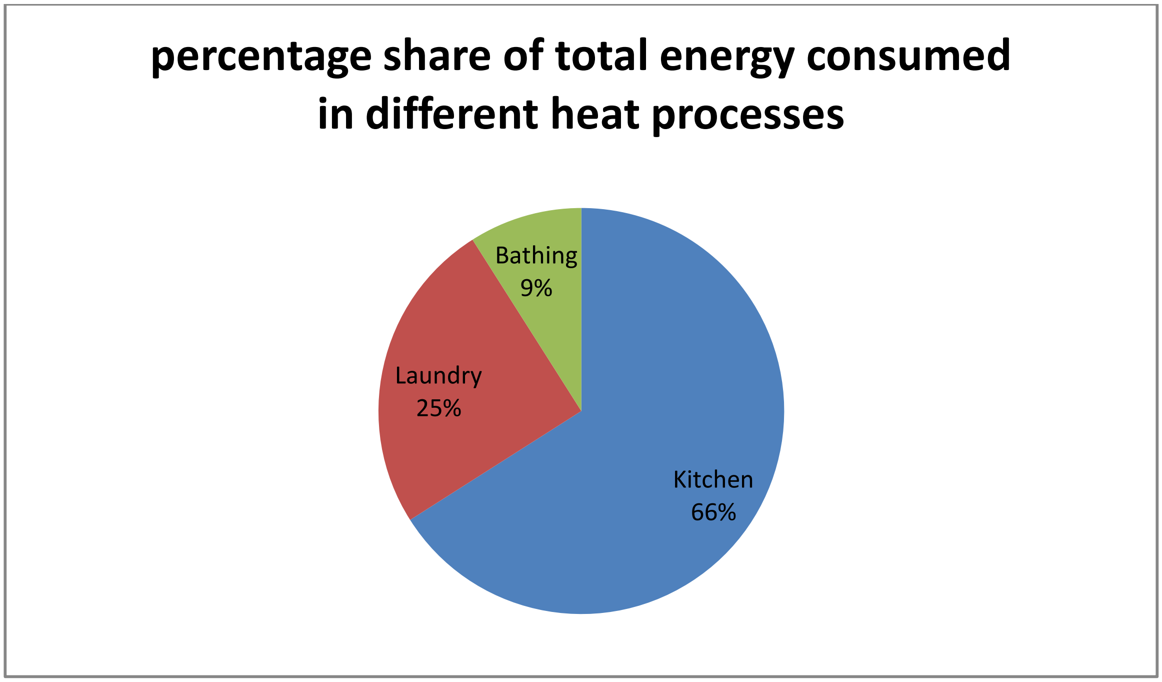

Figure36: - share of total energy consumption in different heat processes

Situation Analysis

In giving an extensive assortment of administrations, extravagance, comfort, stimulation, and items, the accommodation business expends a gigantic measure of energy. An expansive piece of this energy is in thermal state and is still provided by petroleum derivatives. Diverse methodologies can be taken in endeavouring to join solid monetary comes back with ecologically mindful exercises.

With the ascent in mindfulness levels about the renewable wellsprings of energy, businesses are additionally winding up plainly more eco-delicate. Some of them are even intrigued to discover what energy sources does a hotel utilize and what measure of destructive gasses it transmits in the climate. The tourism business must react with energy productive hotel and resort.

Methods that can be implemented

Today there are answers available for hospitality industry which are prepared to think green, are visionary and are prepared to put resources into the fate of their business and in addition the worldwide environment. Adjusting to renewable wellsprings of energy is a standout amongst the most useful and sensible long term choices that any organization can take **[36]**. A substantial part of the energy needs in hotels can be taken into account by solar energy innovations. The utilization of a suitable solar energy for different applications can positively affect the Indian energy.

Flow of Operation

The process of generating steam & hot water with the help of solar paraboloid dish is as explained in the figure.

1. Toward the begin of the day, the Dish takes water from the feed water tank to produce steam at 175°C and pressure of 5 to 8 bars.
2. Steam delivery from dishes to different applications begins when the required steam delivery pressure i.e. of 6 bars and 160°C is accomplished.
3. The steam is filled to the Common Header. It gets circulated to different applications from this common header. Without the sun, the diesel based boilers are utilized to provide steam to the common header.

Because of the restricted supplies, high cost and contamination issues related to petroleum derivatives there is an earnest need to make utilization of renewable wellsprings of energy to meet the thermal energy in businesses and also to cool. India is where vast advances in the solar-powered innovations for fulfilling in the thermal energy needs of ventures are occurring. With government sponsorships, the quickened devaluation benefits, and the rising fuel costs, interest in such solar powered thermal system frameworks has turned out to be financially appealing as well.

5.2 SOLAR RESOURCE AVAILABILITY IN DELHI

Direct Normal Irradiance (DNI) resource required for the working of concentrated solar thermal technology is taken from MNRE solar resource data base available on its website. Database is available for latitude and longitude of major cities in India, data is selected for the above stated latitude and longitude. This monthly DNI data will be used to estimate annual generation potential for the solar collectors which can be used to calculate payback period for the system. Following figure gives the monthly average values of DNI at Delhi as follows **[37]**: -

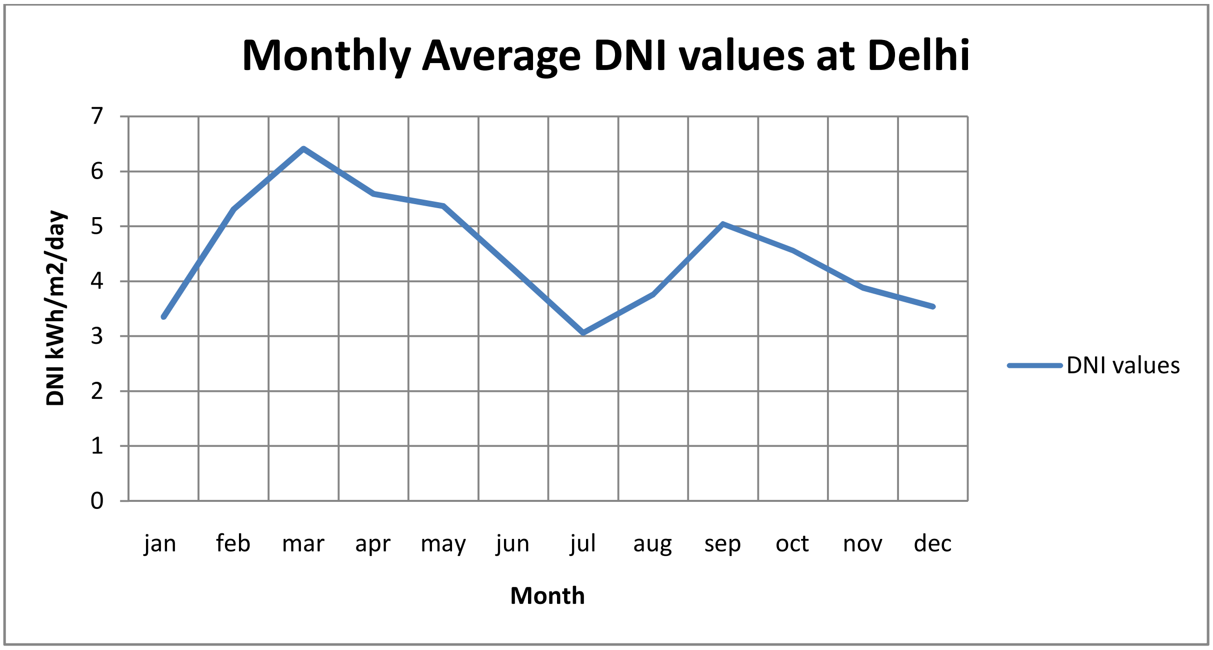

Figure37: - monthly average DNI values for Delhi (source: - NISE)

Average annual value for DNI is 4.53 kWh/m^2/day for Delhi with values highest for March at 6.41 kWh/m^2/day and lowest for august at 3.06 kWh/m^2/day due to monsoon in India. Hence system will work optimally from January to May, and then performance will dip from June to September, then again will perform optimally from October to December.

5.3 INTEGRATION OF SIPH SYSTEM WITH EXISTING STEAM GENERATION AND DISTRIBUTION SYSTEM

Solar paraboloid based process heating system needs to be integrated in existing steam generation and distribution system to make SIPH system more reliable and easy to incorporate. Existing steam system is based on fossil fuel fired boiler and solar thermal collectors are integrated with it via steam pipelines, solenoid valves and pumps, etc. following figure shows the schematic pressure and instrumentation (P&I) diagram for SIPH system for hospitality industry as follows:-

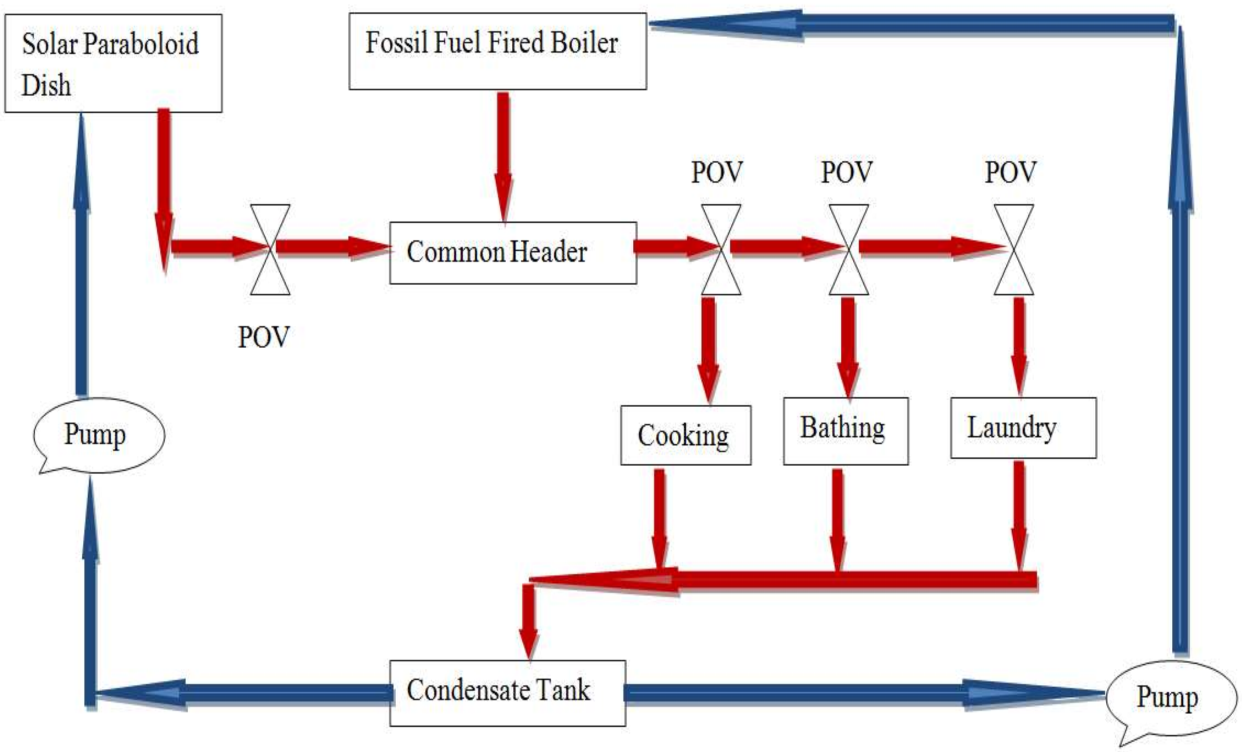

Figure38: - schematic P&I diagram for SIPH system at hospitality industry

Solar paraboloid dish concentrator produces steam at 175^{0}C and 8 bar pressure which is fed to steam insulated pipelines indicated by red arrows along with their direction of flow. Steam now enters the steam separator where steam is separated from water, steam is then send to header pipe and water is send to re-circulation pump to pump it back to receiver. Steam passes through solenoid valve to enter steam distribution header where it is distributed for cooking, bathing and laundry purposes.

Steam after losing its heat gets converted back to condensate which is trapped and sends back to condensate tank via condensate pipe lines indicated by blue arrow. Condensate pump pumps the condensate to feed water tank and make up water is also added to compensate water lost in circuit. Recirculation pump pumps the condensate back to solar collector receiver to complete the circuit. The fossil fuel fired boiler is used as heat source in case on non solar hours as back up or used continuously in night time when solar is not available. Programmable logic circuit based control system is used to control operations of all pumps and solenoid valve based on preset levels of steam temperature and pressure.

CHAPTER 6: ECONOMIC ANALYSIS OF SIPH SYSTEM

After designing the 14 m diameter solar paraboloid dish system for SIPH system for hospitality industry, we integrated the SIPH system into existing steam generation system. Now we discuss the economic feasibility of SIPH system in terms of solar fraction achieved and payback period expected by the hospitality industry for the investment made by them. First Annual energy estimation for the hospitality industry is estimated and also annual energy generation potential for the solar collector array is also estimated.

6.1 TOTAL ENERGY REQUIREMENT OF INDUSTRY

Annual thermal energy requirement for the hospitality industry at Delhi is calculated by multiplying plant working hour in a day with number of working days in a year and also with thermal energy required in KWh for each day.

Table13: - design calculation procedure for annual energy estimation for hotels

Month	No. of working days of industry	Amount of thermal energy required per day (kWh)	Solar Plant working hour in a day	Monthly thermal units required by industry (Kwh)
Jan	31	400	9	111600
Feb	28	400	9	100800
Mar	31	300	9	83700
Apr	30	300	9	81000
May	31	300	9	83700
Jun	30	300	9	81000
Jul	31	300	9	83700

Aug	31	300	9	83700
Sep	30	300	9	81000
Oct	31	300	9	83700
Nov	30	400	9	108000
Dec	31	400	9	111600
Total	365			1093500

Hospitality industry works for 365 days in a year. 300 to 400kWh thermal energy is required daily for various heat requirement processes like bathing, cooking and laundry. Also number of working hours of dish per month is also listed in above table which estimates the Annual thermal energy required in plant at 1093500KWh or 1093.5MWh thermal units.

6.2 ESTIMATION OF ENERGY GENERATION POTENTIAL OF SIPH SYSTEM

Annual energy generation potential for single 14 m diameter solar parabolic dish is estimated on the basis of solar resource at the site at Delhi as stated above. Monthly DNI values are stated along with number of sunny days at plant site which are above 300+ for Delhi region. Rated thermal power for one solar dish is 103KW at 1000w/m2 irradiance for design purpose. Monthly thermal units generated by one dish are calculated by multiplying rated thermal power with number of sunny hours in given month. Annual thermal units generated are 142464.45 KWh for one dish or 142.46 MWh. Following table gives the design procedure for calculating annual energy estimation for solar paraboloid dish based SIPH system as follows:-

Table14: - design calculation procedure for annual energy generation for SIPH system

Month	Average DNI values in kWh/m^2/day	No. of sunny days in a month	No. of working hours in a month	Rated thermal power (KW) at	Monthly units generated by one

				1000W/m^2	dish (kWh thermal)
Jan	3.53	24	84.72	103	8726.16
Feb	5.31	23	122.13	103	12579.39
Mar	6.41	28	179.48	103	18486.44
Apr	5.59	29	162.11	103	16697.33
May	5.37	29	155.73	103	16040.19
Jun	4.22	28	118.16	103	12170.48
Jul	3.06	22	67.32	103	6933.96
Aug	3.76	21	78.96	103	8132.88
Sep	5.04	25	126	103	12978
Oct	4.56	25	114	103	11742
Nov	3.88	24	93.12	103	9591.36
Dec	3.54	23	81.42	103	8386.26
Total		301			142464.45

Results of the following table are compiled in the form of the graph of monthly thermal units or kWh produced by 14 m diameter dish. Following curve shows the graph for each month generation potential for solar thermal collector as follows: -

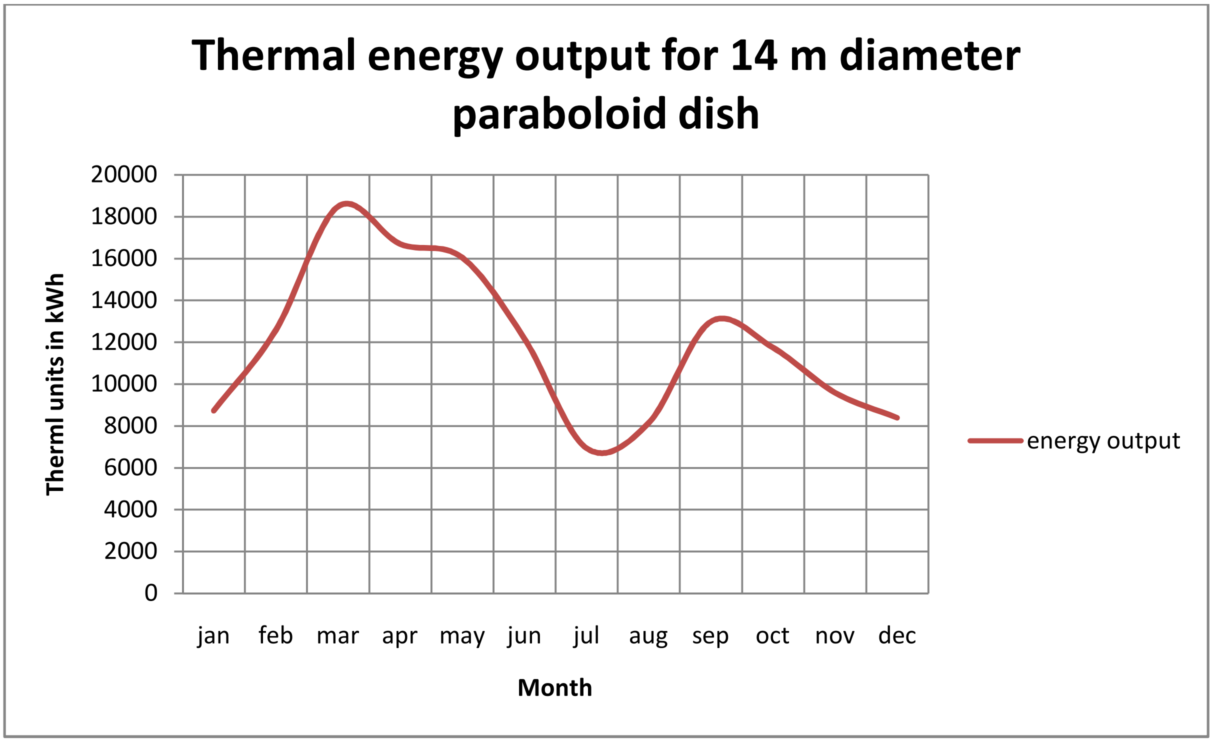

Figure39: - thermal energy generation for one 14 m diameter solar dish

Energy generation remains high for January to May, and then dips from June to August and then rises from September to October to medium then falls low to November and December. This curve follow the same profile as DNI values varies for each month.

Now we have data for total energy required for the plant annually along with energy that can be collected through solar collectors. Now we calculate individually for each month how much energy demand can be met for the plant through solar route i.e. solar fraction defined as ratio of amount of energy generated by solar divided total energy requirement for industry annually, can be estimated.

Month for which performance of solar collectors is high, solar fraction would also be high. Also, during monsoon period performance levels are low. Solar fraction will also be low. Annual average for Solar fraction is calculated by dividing thermal energy output of solar collector array i.e. 142464.45 KWh by annual thermal energy required for the plant i.e. 1093500 KWh which comes around 9.7% i.e. around 10%.

Following data can be represented in the form of parallel bar graphs indicating energy requirements for industry alongside with energy generation levels for each month.

Following figure shows the monthly solar fraction values for SIPH system at Delhi site as follows:-

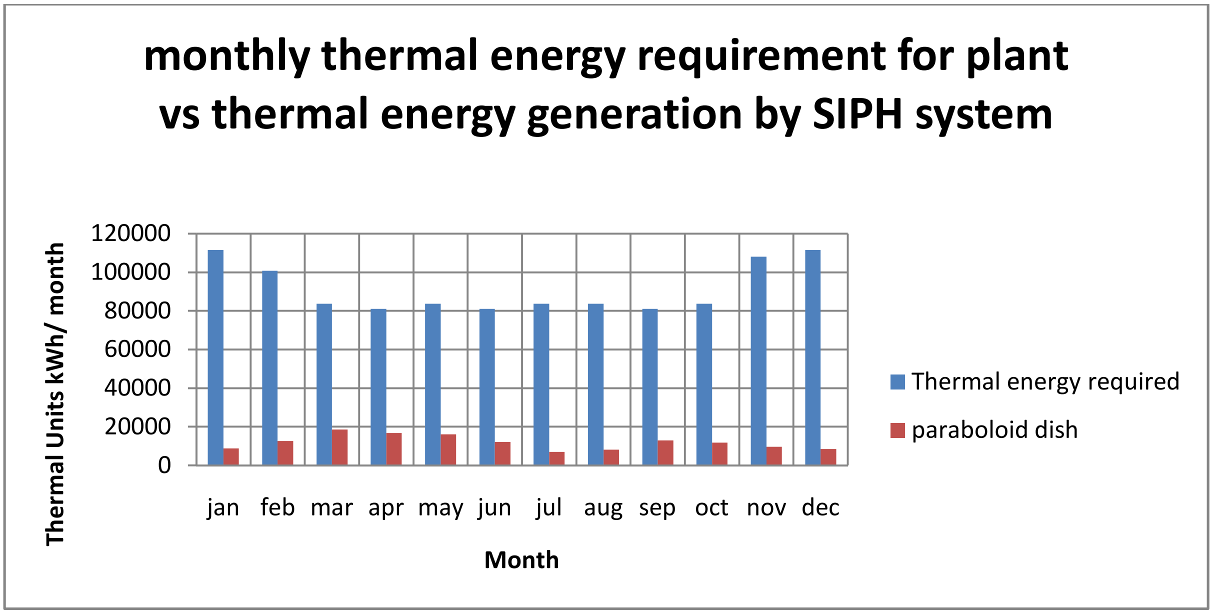

Figure40: - monthly thermal energy requirement VS generation for SIPH system at Delhi

6.3 CALCULATION OF PAYBACK PERIOD ESTIMATION

After designing the solar paraboloid dish based SIPH system and integrating the system into existing steam system at Delhi site, we estimated the solar fraction possible for the system. Finally Economic analysis for the SIPH system should be done by estimating the annual savings due to use of solar energy for replacing fossil fuels for thermal energy requirement.

Cost of currently used fossil fuels in hospitality industry for thermal energy requirement is as follows: -

- **Electricity charges: - ₹9/-per KWh** with taxes (Industrial connection at 11KV from BSES Rajdhani Power Limited)
- **Natural Gas charges: - ₹5/-per KWh** with taxes (Industrial connection from Indraprastha Gas Limited)

As stated above break down for both sources of fuel is 59% for electricity and 41% for natural gas for energy demand fulfilment. Therefore, levelized cost of fuel depending on consumption percentage will be calculated as follows: -

Levelized cost of fuel = 0.59 * electricity charge + 0.41 * natural gas charges

= 0.59 * 9 + 0.41 * 5

= ₹ 7.36/- per kWh

This fuel cost of Rs 7.63 /- per thermal unit will be used for calculation of payback period for the system.

Annual thermal energy generation for 14 m diameter solar dish = rated power * annual DNI * Sunny day

= 103 * 4.53 * 301 = 142464.45 kWh

Cost of 154 m^2 solar paraboloid dish = MNRE cost per sq m * aperture area of dish

= Rs 20,000 * 154 = Rs 30, 80,000

Cost of installation of dish at site = Rs 704000/-

Total cost of dish = concentrator cost + installation cost

= 3080000 + 704000 = Rs 37, 84, 000/-

Capital subsidy available for two axes tracking based solar concentration per m^2 as per MNRE standards = Rs 6000/- per sq m

Total capital subsidy available for 154m2 of solar dish = Rs 9, 24, 000

Actual cost to be incurred by industry after cutting subsidy benefits = Rs 28, 60, 000/-

Tax benefits available for industrial consumer under 80% accelerated depreciation rule under income tax act @ 30% central tax rate = actual cost * 0.8 * 0.3

= 2860000 * 0.8 * 0.3 = Rs 6, 86, 400/-

Final investment required for SIPH system, Delhi = actual cost – tax benefits

= 2860000 – 686400 = Rs 21, 73, 600

Cost of fuel source (mix of electricity and natural gas) = Rs 7.36 /-

Annual savings due to installation of SIPH system for hospitality industry = annual energy generation * fuel cost

= 142464.45 * 7.36 = Rs 10, 48, 538/-

Payback period for SIPH system = final investment made / annual savings due to solar energy

= 2173600 / 1048538 = 2.07 years

Following table shows the calculation steps for the payback period estimation of solar paraboloid dish based SIPH system in Delhi as follows: -

Table 15: - calculation table for payback period for SIPH system at Delhi

Design Parameters Description	**Design Values**
Rated power of 14 m diameter solar paraboloid dish at 1000 W/m^2	103 KW
Average annual DNI value for Delhi	4.53 $kWh/m^2/day$
Annual no. of clear sunny days in Delhi	301
Annual thermal energy generation for 14 m diameter solar dish	142464.45 kWh
Specific thermal energy requirements for all processes	350kWh/day
Annual thermal energy requirements	1093500 kWh

Solar fraction achieved for designed SIPH system (annual energy generation / annual energy requirements)	9.6%
Concentrating aperture area of dish	154m^2
Cost of two axes tracking based solar concentrator per m^2 as per MNRE standards	Rs 20, 000/-
Cost of 154 m^2 solar paraboloid dish	Rs 30, 80 , 000/-
Cost of installation of dish at site i.e. civil foundation work, steam piping work and annual operation and maintenance charges @ 20% of total project costs as per MNRE standards	Rs 704000/-
Total cost of 154m^2 solar dish	Rs 37, 84, 000/-
Capital subsidy available for two axes tracking based solar concentrator per m^2 as per MNRE standards	Rs 6000/- per sq m
Total capital subsidy available for 154m2 of solar dish (= capital subsidy @ per sq m * total sq m installed	Rs 9, 24, 000
Actual cost to be incurred by industry after cutting subsidy benefits	Rs 28, 60, 000/-
Tax benefits available for industrial consumer under 80% accelerated depreciation rule under income tax act @ 30% central tax rate = (actual cost * 0.8 * 0.3)	Rs 6, 86, 400/-
Final investment required for SIPH system, Delhi = actual cost – tax benefits	Rs 21, 73, 600

Cost of fuel source (mix of electricity and natural gas)	Rs 7.36 /-
Annual savings due to installation of SIPH system for hospitality industry	Rs 1048538
Payback period for SIPH system (= final investment made / annual savings due to solar energy)	2.07 years

CHAPTER 7: RESULTS, CONCLUSION AND RECOMMENDATIONS

After studying the energy consumption profile of hospitality industry and its heat process flow chart, we designed the solar paraboloid dish based industrial process heating system. This SIPH system was integrated into the existing hospitality industry steam generation and distribution network. Finally economic analysis of designed SIPH system was done to show its economic viability. In this chapter we compile the results of the present work along with conclusions and future recommendations if any.

7.1 RESULTS OF THE PRESENT WORK

Result of the performance of 14 m diameter solar paraboloid dish at Delhi site has been compiled in the form of the table with major parameters mentioned like physical dimensions of the paraboloid dish, energy generation potential of single dish and complete array, total energy requirement for plant, integration within plant, costing of the installation of SIPH system and its economic analysis in the form of payback period. Following table shows the results of the present work titled **Design of Solar Concentrator based Mechanical Process Heat Application in Hospitality Industry** as follows:-

Table16: - result table of present work of SIPH system for Delhi

Design parameter description	Design values
Rim angle of paraboloid dish	45^0
Focal length to diameter ratio	0.58
Focal length of receiver	8.16
Reflectivity of solar grade mirror	0.92
Angle of incidence	0

Un shaded aperture area fraction	0.92
Capture fraction of the receiver	0.9
Transmittance of the receiver	0.9
Absorptance of the receiver	0.9
Overall heat loss coefficient at 8.3m/sec wind velocity	31
Receiver operating temperature	175
Geometric concentration ratio of dish	205
Equivalent radiative conductance	50%
Useful heat gain rate at 1000W/m2	103KW
Rated steam delivery condition from paraboloid dish	175^0C, 8 bar
Steam enthalpy at 175^0C , 8 bar	2773.1 KJ/kg
Rated steam delivery output	130 KG per hour
Peak overall system efficiency at 1000W/m2	61.4%
Average annual DNI in Delhi	4.53
No. of sunny days in a year	301
Annual thermal units generated by dish	142464.45 kWh
Annual thermal energy requirement	1093500 kWh
Cost of fuel replaced per unit	Rs 7.36/-
Total cost of solar dish	Rs 37, 84, 000/-

Cost incurred after subtracting subsidies and associated tax benefits	Rs 28, 60, 000/-
Total annual saving due to SIPH system	Rs 1048538
Payback period of project	2.07 years
Solar fraction achieved by SIPH system	9.6%

7.2. CONCLUSION AND RECOMMENDATIONS

Finally the technical feasibility of the solar process heating system for the industry has been proved along with its economic feasibility. Thus solar paraboloid based SIPH system can be installed at various hospitality industrial plants with region of high DNI values to make hospitality industry more environment friendly by reducing green house gas (GHG) emissions. Also SIPH system will help companies' dependence of quickly depleting fossil fuels for thermal energy requirements and save them from highly fluctuating fossil fuel prices. Particularly hospitality industry is suitable for this type of concentrating solar thermal technology because of following reasons:-

- Hospitality industry is usually spread over acres of area with vast shade free rooftops available which make them viable for large collector areas.
- Hospitality industry falls under industrial consumer category which is charged heavily for energy prices. Hence solar thermal technology can provide these industries with energy at very cheap prices.
- Hospitality industry is run by big corporate houses which have no capital problem associated with them. So they can bear the initial high investment cost required for SIPH system.

Also SIPH system can be used for other huge energy consuming industries like pharmacy sector, textile sector, food and beverages sector, paper and pulp sector, etc. For future, hospitality industry can install other types of solar technologies for eco friendly environment.

However major challenges still exist against the growth of Concentrated solar heat (CSH) in industrial sector which can be addressed by the recommendation as listed below: -

- Government should promote local manufacturing of components required for concentrated solar technology like solar grades high reflective mirrors; microprocessor based tracking systems, etc under Make in India programme to meet growing demand for CST.
- Government should set targets for the CST annually like targets set for photovoltaic or wind power and take commitments from various public and private sector companies at event like RE Invest. This will help to expand CST nationally.
- Government should make mandatory installation of CST for industries with area covered more than 10 acres to generate 10% of their thermal energy requirements from solar route or else pay fine for not complying with the rule.
- Government should promote new startup companies in the field of CST under Stand up India programme by providing tax benefits, easy company registration process to expand CST nationally on the same line as of photovoltaic.

REFERENCES

1. India Energy Outlook 2016 published by International Energy Agency (IEA), New Delhi, April 2016.
2. India energy outlook 2016 by International Energy Agency (IEA), New Delhi, April 2016.
3. Journal of Hospitality Application and Research, Volume 6 Issue 2, 2015
4. www.hvs.com/article/5002/indian-hotel-industry-survey-2009-10
5. Martin haagen, Christian zahler, zimmermann, Mahmoud M R Al- Nanjami, "solar process steam for pharmaceutical industry in Jordan" international conference on buildings and industry, SHC 2014, energy procedia 70(2015) 621-625
6. Oliver Iglauera , Christian Zahler, "A new solar combined heat and power system for sustainable automobile manufacturing", International Conference on Solar Heating and Cooling for Buildings and Industry, SHC 2013 energy procedia 48 (2014) 1181 – 1187
7. Franz Mauthnera , Matthäus Hubmanna , Christoph Brunnera , Christian Fink, "Manufacture of malt and beer with low temperature solar process heat", International Conference on Solar Heating and Cooling for Buildings and Industry, SHC 2013, energy Procedia 48 (2014) 1188 – 1193.
8. Thiago P Lima, Jose carlos C dutra, Ana rosa M primo, janardan rohtagi, Alvaro Antonio V ochoa, "solar water heating system for hospital laundry: a case study" solar energy 122 (2015) 737-748.
9. Ricardo silva, Franciso Javier Cabera, Manuel Perez Garcia, " process heat generation with parabolic trough collectors for a vegetable preservation industry in southern Spain" , International Conference on Solar Heating and Cooling for Buildings and Industry, SHC 2013, energy Procedia 48 (2014) 1210 – 1216.
10. Christian zahler, Oliver lglauer, "solar process heat for sustainable automobile industry" SHC 2012, energy procedia 30(2012) 775-782.

11. Marco Calderoni, Marcello Aprile, Salvatore Moretta, Aristotlis Aidonis, Mario Motta, “solar thermal plants for industrial process heat in Tunisia: economic feasibility analysis and ideas for new policy” SHC 2012, energy Procedia 30 (2012) 1390 – 1400.
12. A Ferin, M Caldeoni, M motta, “solar thermal plant integration into an industrial process” , International Conference on Solar Heating and Cooling for Buildings and Industry, SHC 2013, energy Procedia 48 (2014) 1152 – 1163.
13. C. Lauterbach, B Schmitt, K Vajen, “system analysis of a low temperature solar process heat system”, solar energy, volume 101, March 2014, pages 117-130.
14. R J Fuller, “solar industrial process heating in Australia – past and current status” renewable energy, volume 36, issue1, January 2011, pages 216-221.
15. Wang M., Siddiqui K., “The impact of geometrical parameters on the thermal performance of a solar receiver of dish-type concentrated solar energy system”, Renewable Energy 35 (2010) 2501-2513.
16. Ashmore M., Simeon H. T., “Experimental energy and exergy performance of a solar receiver for a domestic parabolic dish concentrator for teaching purposes”, Energy for Sustainable Development (2014).
17. Reddy K.S., Veershetty G., “Viability analysis of solar parabolic dish stand-alone power plant for Indian conditions”, Applied Energy 102 (2013) 908–922.
18. Reddy K.S., Kumar N. S., “Convection and surface radiation heat losses from modified cavity receiver of solar parabolic dish collector with two-stage concentration”, Heat Mass Transfer (2009) 45:363–373.
19. Reddy K.S., Kumar N. S., “Convection and surface radiation heat losses from modified cavity receiver of solar parabolic dish collector with two-stage concentration”, Heat Mass Transfer (2009) 45:363–373.
20. Wu S., Xiao L., Cao Y., Li Y., “Convection heat loss from cavity receiver in parabolic dish solar thermal power system”: A review, Solar Energy 84 (2010) 1342–1355.
21. Wu S., Xiao L., Cao Y., Li Y., “A parabolic dish/AMTEC solar thermal power system and its performance evaluation”, Applied Energy 87 (2010) 452–462.

22. Barlev D., Vidu R., Stroeve P., "Innovation in concentrated solar power, Solar Energy Materials & Solar Cells" 95 (2011) 2703–2725.
23. Kaneko H., Miura T., Ishihara H., Taku S., Yokoyama T., Nakajima H., Tamaura Y., "Reactive ceramics of CeO_2–MOx (M ¼ Mn, Fe, Ni, Cu) for H_2generation by two-step water splitting using concentrated solar thermal energy", Energy 32 (2007) 656–663.
24. Kalogirou S. A., "Solar thermal collectors and applications, Progress in Energy and Combustion Science" 30 (2004) 231–295.
25. H P Garg, J Prakash, Solar Energy: Fundamentals and Applications, Mc Graw Hill Education, 2013 edition.
26. Technical study report on Solar heat for industrial processes (SHIP) state of the art in the Mediterranean region, GEF.
27. S P Sukhatme, J K Nayak, Solar Energy: principles of thermal collection and storage, Mc Graw Hill Education, 2014 edition.
28. www.powerfromthesun.net, Book, chapter 11, Energy storage.
29. Ministry of new and renewable energy (MNRE), www.mnre.gov.in, retrieved on 20th April, 2017.
30. Paraboloid dish based solar system Operation & Maintenance Manual, UNDP – GEF project on concentrated solar heat, MNRE, November 2014.
31. A compendium of solar dish technology, William B. Stine, California state polytechnic University, Richard B. Diver, Sandia National laboratory, January 1994.
32. Engineering Toolbox/Convective Heat transfer, www.engineeringtoolbox.com, retrieved on 19th April 2017.
33. Indian Solar resource map, National institute of solar energy (NISE), Ministry of New and Renewable Energy (MNRE).
34. K. Sivakumar, N. Krishna Mohan and B. Sivaraman "Performance analysis of elliptical heat pipe solar collector" Indian Journal of Science and Technology.
35. India cleantech summit presentations on day 3,http://www.indiacleantechsummit.com/presentations/day3/ParallelSessionV_RETThermalApps/Veena_Sinha.pdf

36. A market for renewable energy credits in the Indian power sector, by Anoop Singh : in Science Direct Renewable and Sustainable Energy Reviews 13 (2009): 643–652.
37. National Institute of Wind Energy (NIWE), www.niwe.res.in