# MODELING, ANALYSIS, EVALUATION AND SELECTION OF FLAT PLATE LIQUID SOLAR COLLECTOR SYSTEM

## A

## THESIS

**Submitted in the partial fulfillment of the requirement for the award of degree of**

**Master of Engineering**

**in**

**Thermal Engineering**


**Submitted by**

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**UNDER THE GUIDANCE OF**


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**JULY 2012**

# DECLARATION

I hereby declare that the thesis entitled **"MODELING, ANALYSIS, EVALUATION AND SELECTION OF FLAT PLATE LQUID SOLAR COLLECTOR"** is an authentic record of my study carried out as requirement for the award of degree of **Master of Engineering (Thermal Engineering)** at **Thapar University, Patiala** under the guidance of **Dr. V.P. AGRAWAL**, visiting Professor, Department of Mechanical Engineering, Thapar University, Patiala during **July 2011 to June 2012.** The matter embodied in this report has not been submitted in part or full to any other university or institute for the award of any other degree.

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This is to certify that above declaration made by the student concerned is correct to the best of my knowledge and belief.

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# Abstract

Solar energy is the best alternative to fulfill the increasing energy demand and to overcome the drawbacks of conventional sources like environment pollution. Flat plate solar collector is the device used to convert solar energy into heat energy. Flat plate liquid solar collectors are the most commonly used collectors today all over the world in commercial and domestic water heating applications. However researches are going on to make this collector useful for other applications like water distillation, heat pump, solar cooling system, effluent evaporation system, solar oven etc. A number of models are developed by different researchers to evaluate the only thermal performance of the system. Thermal performance is the important factor but not only sole criteria for the selection of FPLSC.

A new procedure is developed for the selection and evaluation of flat plate liquid solar collector (FPLSC) using multi attribute decision making approach. A cause and effect diagram is developed for the attributes identification, those are sufficient to describe the system. Attribute based characterization of the systems make the classification of the systems more precise. Coding of attribute is done to convert the information into useful form. Information developed from the quantification of attributes is useful to the designer, manufacturer and the user in their respective areas. The three stage selection procedure is used for the evaluation and ranking of the FPLSC system. First the limited numbers of alternative systems are sorted out on the basis of user requirements using elimination search. Weighted normalize matrix is developed for the selected systems in the 2$^{nd}$ step which takes into account of the relative importance of attributes. TOPSIS and graphical techniques (spider and line graph) are applied for the evaluation and ranking of the systems in step 3$^{rd}$. This methodology is explained with an illustrative example. The results obtained from the three techniques are not consistent with each other. Further sensitivity analysis is carried out to see the effect of individual attribute on the ranking of FPLSCs. Sensitivity results come from the three techniques are also different. So it is concluded that results from the TOPSIS are taken to be right as it is the standard procedure for the evaluation and ranking of systems. Graphical techniques are inconsistent with the TOPSIS so do not use these for the selection purpose. These techniques can be used for the visual inspection of the systems. Final selection of FPLSC system is not only the basis of ranking of the systems. The final selection is made by the management by considering other factors effecting the selection. This approach is useful to designer and manufacture to get the information about the attribute those are more useful for the selection of FPLSC so that those attributes are considered more while designing and manufacturing.

A structural model of the FPLSC is developed using graph theoretic approach to analyze the FPLSC from different prospective. The different constituents and the interaction between the constituents are identified. A graph is developed which represent the constituents and the interactions between the constituent. The information of the graph is converted into matrix form. Further this information of the graph is converted into a mathematical function using

matrix algebra. This function includes the effect of all constituents and the interaction between the constituents. If the information about the FPLSC structure is in qualitative form then this function is used for the comparison of the different FPLSCs. If the information of FPLSC structure is given in numerical values then this function is useful to analyze the different FPLSC properties like quality, reliability etc.

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# Chapter-1
# Introduction

Energy consumption increases very rapidly as the world developing. Conventional sources are not able to fulfill the today energy needs. Fossil fuels are the main conventional sources for energy production till now. The two main limitations of fossil fuels: Limited in quantity and environment pollution makes the world think for alternative energy sources. Renewable energy sources eliminate the weaknesses of conventional sources. But because of less knowledge about these sources and high initial cost of the conversion systems limits the use of these resources. From the renewable energy resources, solar energy has a huge potential for the fulfillment of today energy needs. The total solar radiation energy falling on earth atmosphere is $10^{17}$ watts [1]. Amount of solar radiations reaches earth is $10^{16}$ watts, this is 1000 times more than the world energy need. So if 5% of this energy is utilized, this is 50 times of world energy demand.

## 1.1 Solar radiations as an energy source

Sun produces energy by fusion process and transfers it in the form of radiations. As the temperature of the sun is very high so the radiations emitted by the sun have shorter wavelengths as per the Wien's law which state that

$$\lambda \cdot T = \text{constant} \quad (1)$$ [1]

λ – Wavelength of radiation at which hot body radiates maximum energy

T – Temperature of the hot body

Most of the energy radiates by the sun in the visible and infrared region. Small amount of energy radiates in ultraviolet region as shown in the following figure

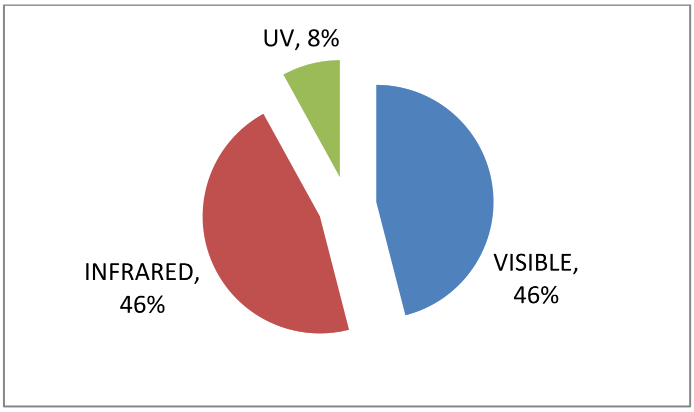


Fig1.1 [1] Energy Distribution per Frequency Band

Standard average intensity (Solar constant) of solar radiation received at the top of atmosphere of earth as per NASA is 1353 watt/square meter [1]. UV radiations are absorbed by the Ozone layer and infrared radiations are absorbed by the water vapors, carbon dioxide. Also the scattering of light occur due to dust particles, air particles, different gases etc. so the intensity of radiation reaches the earth decreases. Radiations reaches on the earth are of two types:

i. Direct (beam) radiation

   Solar radiation not scattered or absorbed and reaches the surface directly from the sun.

ii. Diffuse radiation

   Solar radiation reaches the surface but their direction is changed by scattering and reflection by the atmosphere.

When the sky is clear amount of direct radiation is much higher than the diffuse component (10 to 20% of total radiation) similarly in cloudy day amount of diffuse radiation higher than direct radiation. As per the amount of solar radiation reaches the earth surface depend on the environment conditions which are varying place to place so amount of solar radiation falling on the surface varies. Also the amount of radiation falling on the surface depends on the incidence angle Θ (angle between incident radiation and normal to the surface).

$$\mathrm{Cos}\,\Theta = \sin\varphi \cdot (\sin\delta \cdot \cos\beta + \cos\delta \cdot \cos\gamma \cdot \cos\omega \cdot \sin\beta) + \cos\varphi \cdot (\cos\delta \cdot \cos\omega \cdot \cos\beta - \sin\delta \cdot \cos\gamma \cdot \sin\beta) + \cos\delta \cdot \sin\gamma \cdot \sin\omega \cdot \sin\beta \qquad (2)\ [1]$$

$\varphi$ – latitude, $\delta$ – declination angle, $\beta$ – slope, $\gamma$ – surface Azimuthal angle, $\omega$ – hour angle

$$I = I_n \cdot \cos\theta \qquad (3)[1]$$

Here $I_n$ – intensity at the horizontal surface

$I$ – intensity at the given inclined surface

### 1.2 Applications of solar energy

A number of systems are developed to convert the solar energy into useful for many applications. Table 1.1 is developed to show the various systems for solar energy conversion, application and uses of solar energy.

Table 1.1
Application and uses of solar energy systems

| Type of System | Applications | Uses |
|---|---|---|
| Photo Voltaic panel | Electricity Generation | Residential buildings |
| | | Commercial systems like offices and factories. |
| | | Different industry applications |
| | | Remote buildings like colleges and clinics |
| | | Water pumping |
| | | Street lights |
| Hybrid system(PV panel links with diesel engine) | Electricity Generation | High power demand loads |
| Soar still | Distillation | Produce fresh water from the saline water, where the fresh water is not available. |
| Solar cooker | Cooking | Used in homes for to cook different foods |
| | Steam generation | |
| Solar Collectors | Solar water heater | Residential water heating |
| | | Industrial process heat |
| | | Space air heating |
| | | Drying agriculture products |
| | Solar air heater | Space air heating |
| | | Drying agriculture products |
| | Solar cooling | Space cooling |
| | Electricity generation | Different industrial and residential power demands |

| | | |
|---|---|---|
| | Solar Furnace | Hydrogen fuel production |
| | | High temperature material testing |
| | | Melting of materials in foundry shop |
| | | Electricity production |
| | Steam generation | Industrial process heat |
| Solar ponds | Store solar energy in the form of heat | Electricity generation |
| | | Industrial process heat |
| | | Desalination |
| | | Heating and cooling buildings |
| Passive solar building design | Maintain the building inside temperature comfortable | Uses in residential buildings, offices |
| | Solar light | Building lighting |

### 1.3 Solar Collectors

Solar collectors are the devices used to convert solar energy into heat energy. Solar collector with associate absorber (absorb the solar radiation) collects and converts the solar energy into heat energy that can be used in many applications. Fig.1.2 shows the working principal of solar collector.

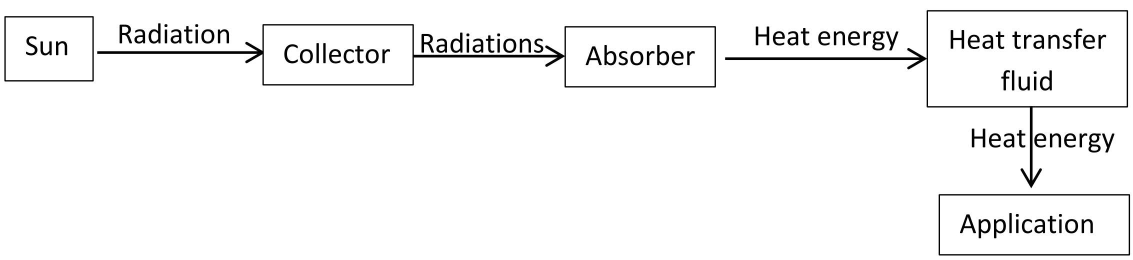


Fig 1.2 Working Principle of solar collector

In the fig 1.3 some collectors are given which are used for to convert solar energy into heat energy with their approximate working temperature range.

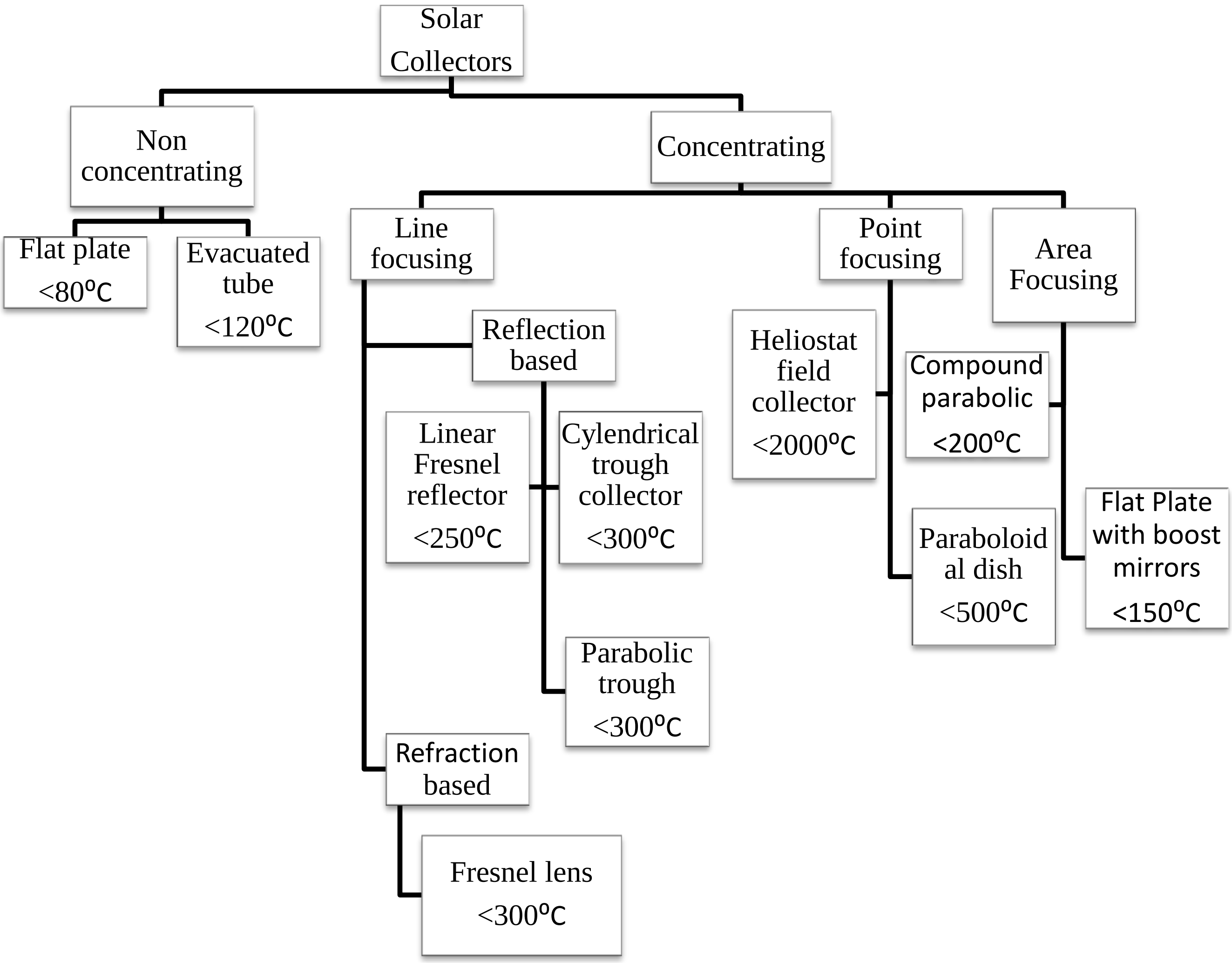


Fig 1.3 Types of Solar Collector

In non-concentrating type collectors' collector area is equal to absorber area. These are mostly used for low temperature (<120$^0$C) heating purposes for e.g. heating water in the houses, hospitals, restaurants, hotels and solar air heating for to preheat air in buildings. Advantages of non-concentrating collectors over the concentrating collectors are: low maintenance, use both diffuse and beam radiations, no tracking system required, easy to operate and high reliability. Non concentrating collector can produce high temperature but because of following reasons these are not used for high temperature application:

i. The cost of absorber higher than the cost of mirrors.
ii. The heat losses from the collector are proportional to the absorber area.
iii. Radiative losses are proportional to $T^4$ so there is great increase in radiative loss due

to high temperature.

In concentrating collectors the solar radiations falling on large area (collector) are concentrated on the small area (absorber). Thus the energy falling per unit area increases on the concentrating surface as compare to any other surface. This increases the energy input rate per unit area due to which high temperatures can be achieved. So point focusing collectors are used for much higher temperature applications. The ratio of collector area to absorber area is the parameter decides the achievable temperature rise. The following table 1.2 shows the different concentrating collectors with their achievable concentration ratios. From the table 1.2 it is clear that point focusing collectors has highest concentration ratio, so use for high temperature applications.

Table 1.2 [2]
Solar Concentrating Collector Specifications

| Collector type | Description | Relative thermodynamic efficiency | Operating temp. range ($^0C$) | Relative cost | Concentration ratio | Technology maturity | Tracking (Axis) |
|---|---|---|---|---|---|---|---|
| PTC | Parabolic sheet of reflective material(aluminum, acrylic)<br><br>Linear receiver (metal pipe with heat transfer fluid) | Low | 50-400 | Low | 15-45 | Very mature | One |
| Linear Fresnel | Linear Fresnel mirror array focused on tower or high mounted pipe as receiver | Low | 50-300 | Very low | 10-40 | Mature | One |
| Solar tower | Large heliostat field with tall tower in its center<br><br>Receiver: water/HTC boiler at top<br><br>Can be used for continuous thermal storage | High | 300-2000 | High | 150-1500 | Most recent | Two |
| Dish-Stirling | Large reflective parabolic dish with stirling engine receiver at focal point<br><br>Can be used with/out HTC, if heat engine produces electricity directly from reflected thermal energy (in this case, thermal storage cannot be achieved by the system) | High | 150-1500 | Very high | 100-1000 | Recent | Two |

### 1.3.1 Flat plate solar collectors

It is the non-concentrating type collector. This is used for low temperature heating applications. Domestic solar water heater is the main example of its use. These collectors are more reliable, simple in operation and low maintenance required. These collectors are widely used all over the world. The other applications of this collector are pool heating, laundry, space heating, drying agriculture products etc. Unglazed collectors are used for pool heating because of low temperature requirement. On the basis of type of fluid used for heat transfer flat plate collectors are classified as: liquid type flat plate solar collector and solar air heater. Fig.1.4 shows the different components of flat plate solar collector.

There are five main components of FPLSC are: absorber, transparent cover, insulation, flow tubes and casing. Solar radiations are absorbed by the absorber plate. Absorptivity of the absorber plate needs to be high so that maximum amount of solar radiations can be absorbed. Selective surfaces are used to increase the absorptivity of the absorber plate. Different types of selective surfaces are: selective coating, directional selectivity, interference filters. Absorbed radiation energy converted into heat after absorption. This heat energy is transferred from the absorber plate to flow tubes. So the thermal conductivity of the system needs to be higher. The properties required for the selection of the absorber plate are: thermal properties, chemical properties, mechanical properties and optical properties.

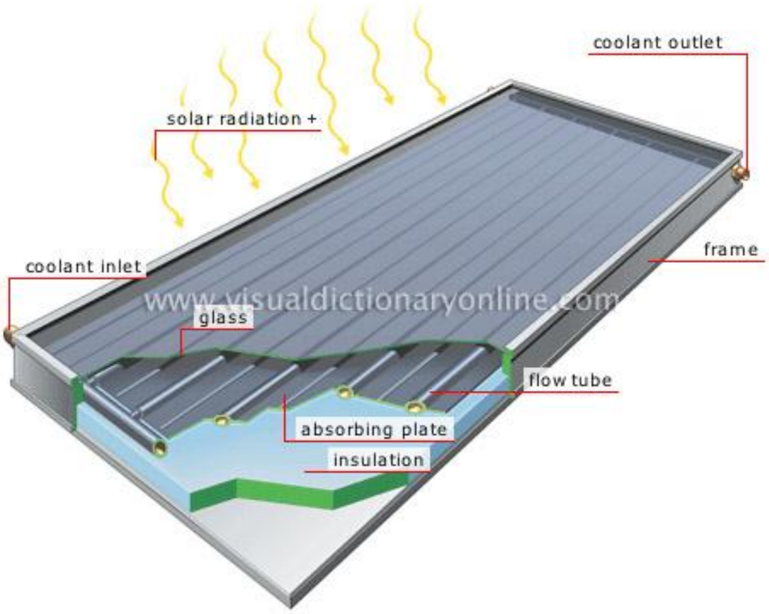

Fig 1.4 [3] Flat plate liquid solar collector

### 1.3.2 Evacuated tube solar collector

Evacuated tube is the non-concentrating type collector as shown in fig 1.5 Absorber tube is enclosed in the glass tube. Space between the glass tube and absorber is evacuated to reduce the thermal losses. Fluid is converted into steam due to heating in the absorber tube. High temperature vapors moves upward and cooled by the fluid flow in the manifold. Heat of the vapors is transferred to the useful fluid. This collector is used for low temperature applications like domestic water heating, space heating etc.

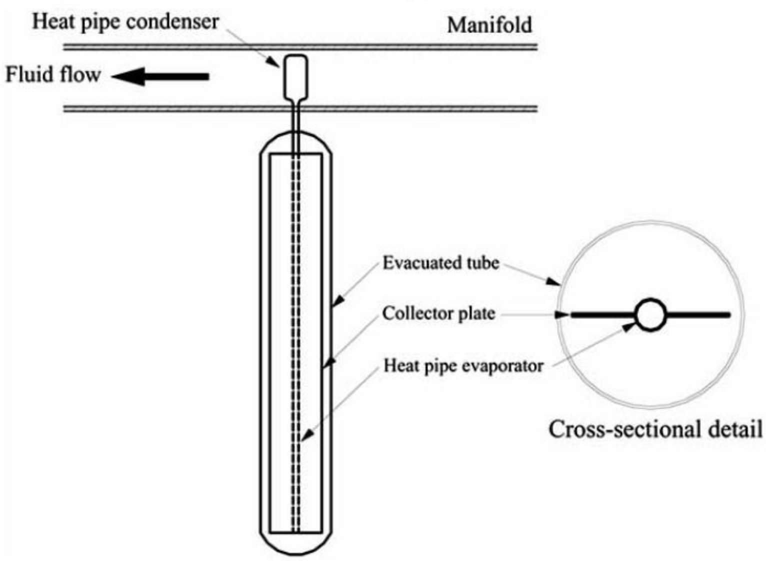


Fig 1.5 [4] Evacuated tube collector

### 1.3.3 Parabolic trough

Parabolic trough is a line focusing collector as shown in fig 1.6.It is used for high temperature applications like steam generation, electricity production, and industrial process heat etc. There are nine large solar power plants that are operating in the California Mojave Desert [5]. These plants are developed by Luz International Limited and referred to as Solar Electric Generating Systems (SEGS). Each plant is in the range 14–80 MW and represents 354 MW of installed electric generating capacity. There are two euro trough models ET100 and ET150 are developed with the optical concentration ratio 82:1 and achievable temperature of $500^0$C [6].

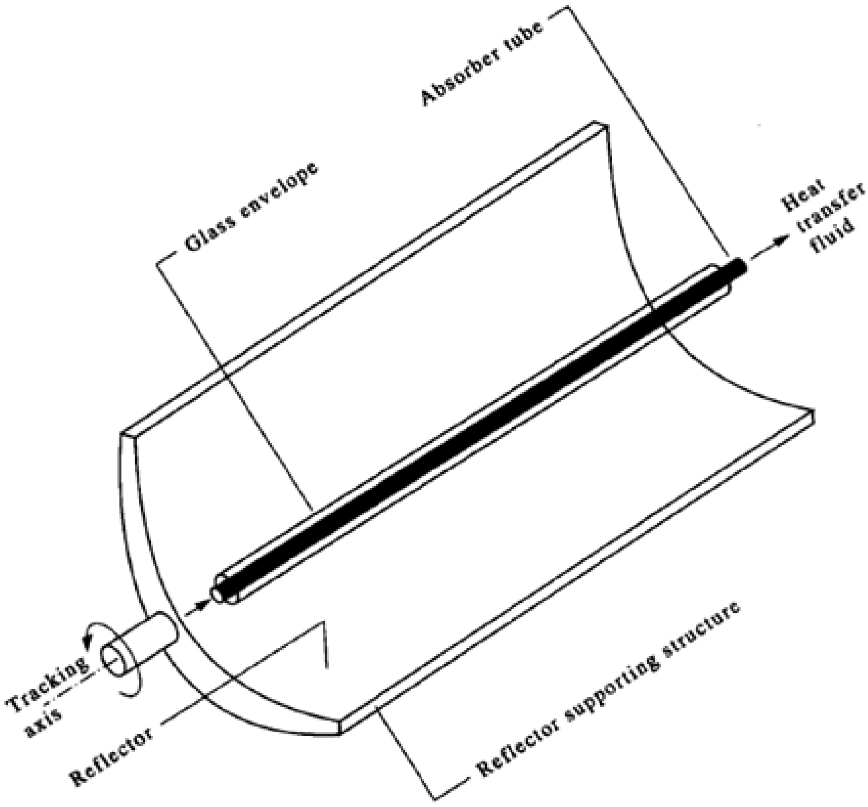


Fig1.6 [7]   Parabolic Trough Collector System

### 1.3.4 Fresnel Lens

It is a line focusing collector as shown in fig 1.7. In this solar radiations are focused by the use of Fresnel lens by the refraction phenomena. It is the alternative for the parabolic trough, because of high cost of the reflector mirrors. A lens made from the low cost plastic can be used for the focusing of solar radiations. But the properties of plastic change with the temperature and UV radiations, limits the use of plastic lens.

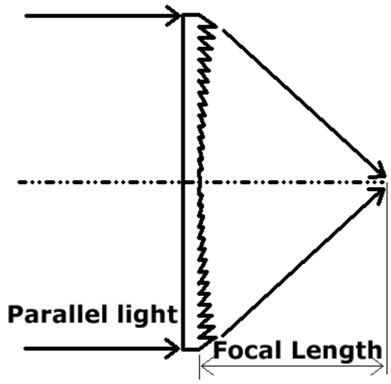

Fig 1.7 [8] Fresnel lens

### 1.3.5 Fresnel Reflector

Small linear reflecting mirrors are used at the place of continuous high cost reflector mirror as shown in fig 1.8. But because of linear shape, spacing between the reflectors increases. Using Fresnel reflector at the place of parabolic trough reduces the efficiency of the system but also reduce the cost of the system.

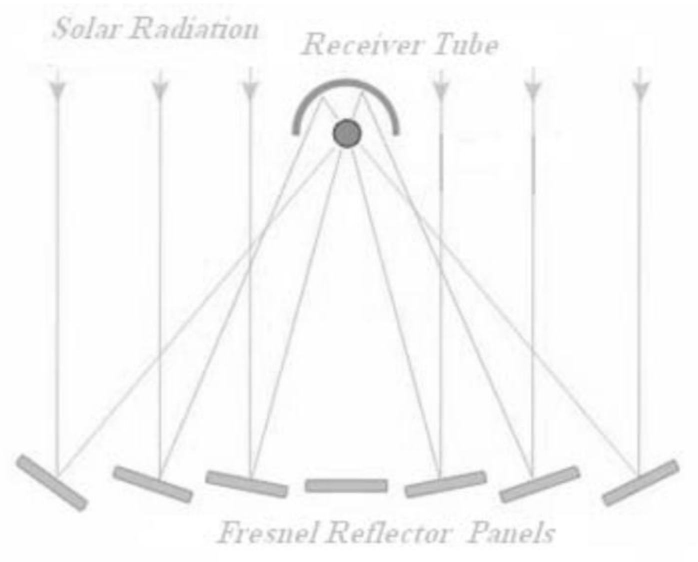


Fig 1.8 [9] Line focusing linear Fresnel reflector

Performance comparison between the parabolic trough and linear Fresnel reflector is shown in table1.3. From the table 1.3 it is clear that annual solar efficiency of the linear Fresnel reflector is less than the parabolic trough.

Table 1.3 [9]
Performance comparison

| Collector | Capacity (MW) | Concentration | Peak solar efficiency (%) | Annual solar efficiency | Temperature output (°C) |
|---|---|---|---|---|---|
| Parabolic trough | 10-200 | 70-80 | 21 | 17-18 | 300-550 |
| Linear Fresnel | 10-200 | 25-100 | 20 | 9-11 | 250-500 |

### 1.3.6 Paraboloidal dish

Paraboloidal dish is a point focusing collector as shown in fig 1.9. It is used for the applications, where temperature requirements are very high like in steam generation. This collector requires two axes tracking for to focus the radiations on the absorber.

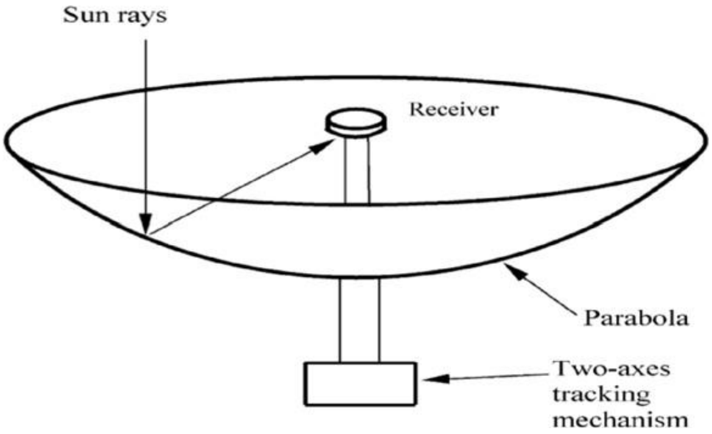


Fig 1.9 [2] Paraboloidal dish collector

### 1.3.7 Central receiver

In this a number of reflecting mirrors with the two axis tracking mechanism are placed around the receiver as shown in fig 1.10. These reflecting mirrors are focusing the radiations at the receiver. These reflecting mirrors are called heliostats. Similar to the paraboloidal dish collector this collector is also used for high temperature applications.

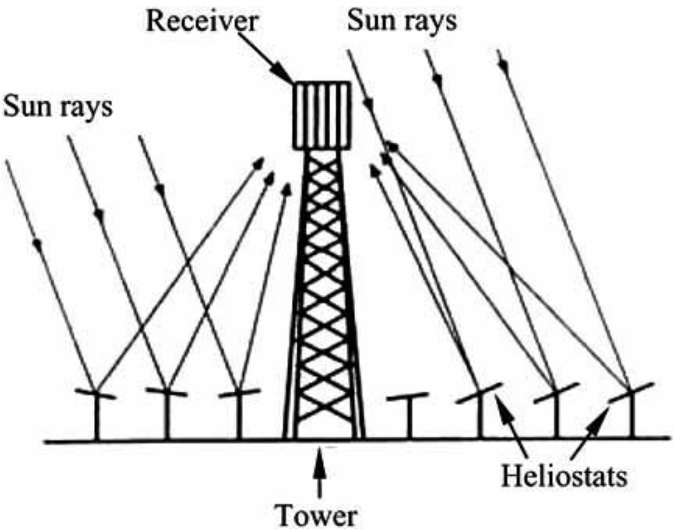


Fig 1.10 [4] Heliostat field collector

### 1.3.8 Compound parabolic collector

This is the modification form of the parabolic collector. In case of parabolic collector, collector needs to focus toward the sun for to concentrate the solar radiation at the focal point. In compound parabolic collector all rays are reflected toward the absorber area as shown in fig. 1.11. As the radiations are not focused at single point, CPC is the non-imaging collector. The benefits of the CPC over parabolic collectors are; no need of tracking and simpler support structure.

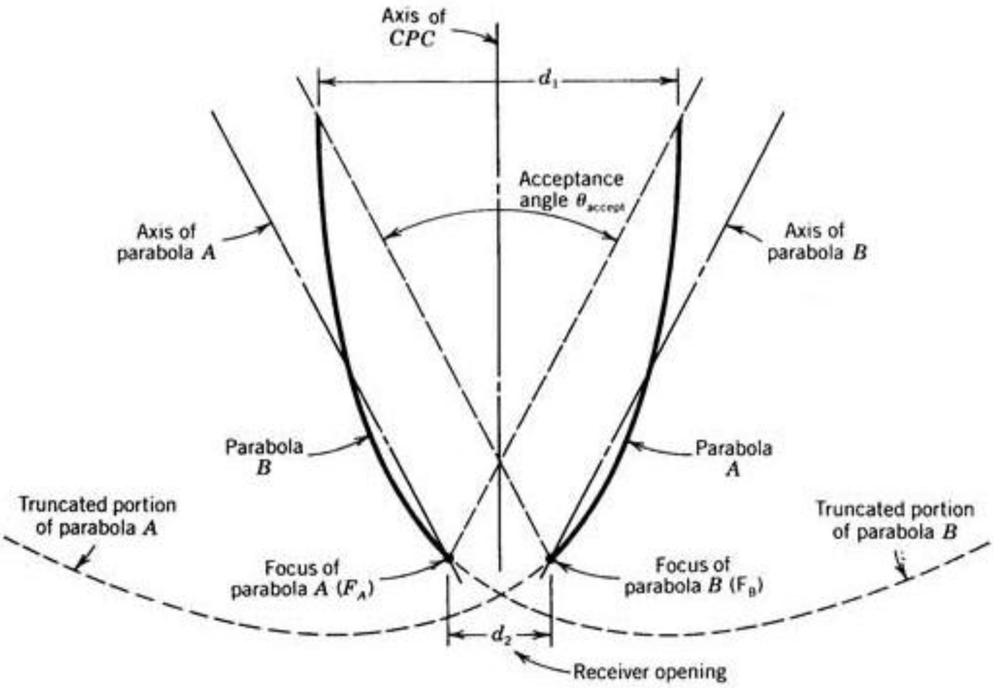


Fig 1.11[10] Compound parabolic collector

## 1.4 Industrial process heating requirements

The 40% of the total power produced in a country is consumed in industry and the 45-65% of this electricity is used in direct thermal applications (process heating purposes) [7]. If we supply directly that heat which is used in process heating by solar energy we can save lot of electric energy. Fig 1.12 shows the distribution of industrial heat demand by temperature level. Data for 2003, 32 countries: EU25 + Bulgaria, Romania, Turkey, Croatia, Iceland, Norway and Switzerland.

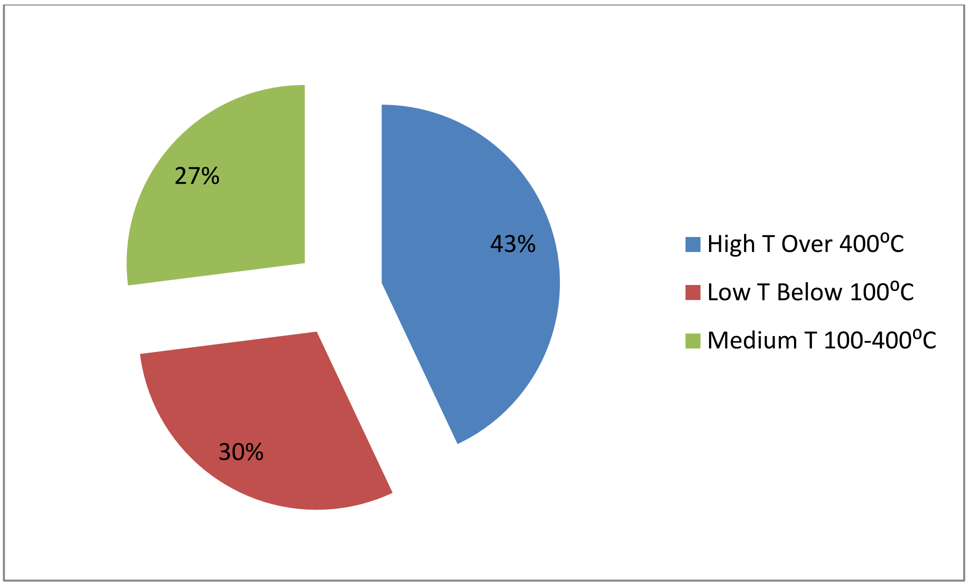


Fig1.12 [11] Heat Demand Distribution per Temperature Range

Various industrial processes with their required temperature range are shown in table 1.4.

Table 1.4 [12]
Temperature requirement for different process heat applications

| Industrial Sector | Process | Temperature level [$^{o}$C] |
|---|---|---|
| Food and beverages | Drying | 30-90 |
| | Washing | 40-80 |
| | Pasteurizing | 80-110 |
| | Boiling | 95-105 |
| | Sterilising | 140-150 |
| | Heat treatment | 40-60 |
| Textile industry | Washing | 40-80 |
| | Bleaching | 60-100 |
| | Dyeing | 100-160 |
| Chemical industry | Boiling | 95-105 |
| | Distilling | 110-300 |
| | Various chemical process | 120-180 |
| All sectors | Pre-heating of boiler feed water | 30-100 |
| | Heating of production halls | 30-80 |

From the [2], [7] and [12], it is clear that a huge amount of energy is consumed for heating applications in industrial sector. Temperatures required for these applications can be achieved by the different solar collectors. Temperatures for different applications are also given that helps in the selection of collector for the applications.

### 1.5 Applications of solar collectors

In solar water heaters mostly non concentrating collectors are used. Solar water heaters are used for the domestic and commercial hot water applications. The approximate cost of 100LPD flat plate collector based system is Rs.22000-26000. The approximate cost of 100LPD evacuated tube system is Rs.15000-18000. Ministry of New and Renewable Energy, Govt. of India is providing 30% subsidy on this scheme i.e. Rs. 6600/- on FPC system and Rs.4500/- on ETC system of capacity 100 LPD. Government of Punjab has made the use of solar water heating systems mandatory in the following type of buildings:

1. Industries where hot water is required for processing.
2. Hospitals and Nursing homes including Government Hospitals.
3. Hotels, Motels and Banquet halls.
4. Jail Barracks, Canteens.
5. Housing Complexes set up by Group Housing Societies/Punjab Urban Development Authority.
6. All residential buildings built on a plot of size 500 square yards and above falling within the limits of municipal committees/corporations and Punjab Urban Development Authority sectors.
7. All Government buildings, Residential Schools, Educational Colleges, Hostels, Technical / Vocational Education Institutes, District Institutes of Education and Training, Tourism Complexes and Universities etc.

Solar water heaters installed in Punjab state are of 16 lac liter capacity according to Punjab Energy Development Agency (PEDA). Major installations of solar water heater by PEDA are:

1. 9500 LPD system installed at Guru Nanak Dev University, Amritsar.
2. 10000 LPD system installed at Army Institute of Law S.A.S Nagar, Mohali..
3. 7500 LPD system installed at North India Hotel & Industries, Jalandhar.
4. 7000 LPD system installed at Hotel City Heart, Ludhiana.
5. 6000 LPD system installed at Surya Educational Institute, Rajpura,
6. 7500 LPD system installed at Shiwalik Public School, Mohali.
7. 13500 LPD system installed at Ranbaxi Industries Ltd., Ropar.
8. 12500 LPD system installed atPunjabBhawan, New Delhi.

9. 13000 LPD system installed at Dashmesh Academy, Anandpur Sahib.
10. 6000 LPD system installed at Surya World Educational research institute, Village Bapror, Rajpura, Distt. Patiala.
11. 8000 LPD Parabolic concentrated type system installed in B.S. Paper Mill, Tajpur, Ludhiana.
12. 6000 LPD system installed at Guru AngadDev Veterinary and Animal Science University Ludhiana.
13. 1 Lac LPD system installed at Kangaroo Industries, Ludhiana.

Solar energy is the better alternative source because of its availability all over the world. A number of systems are developed those replace conventional energy sources by the solar energy in many applications. There are number of solar collectors are available to convert solar energy into heat energy. The temperature requirement is the main criteria for the selection of solar collector in the application. Solar collectors have potential to fulfill the industrial process heating demands. This helps in the saving of electric energy. Solar collectors are easily used in low temperature application because of operating simplicity. Due to which non-concentrating collectors are mostly used. From the non-concentrating collectors FPLSC is much preferable because of its design simplicity, high developed technology and high reliability.

A number of models are there to evaluate only thermal performance of the FPLSC system [31, 36, 43]. The overall performance of FPLSC is not only the thermal performance, there are some other properties of FPLSC are required like reliability, quality etc. Available literature does not provide the overall performance of FPLSC and is only concerned with thermal performance. So there is a need to develop a model for the analysis of different properties of FPLSC. The different properties of the system are the combined effect of its constituents and the interaction between the constituents. The effect of some constituents and interactions between the constituents on the thermal performance of the FPLSC is studied in [14-17, 31, 61]. So a model which represents the constituents of FPLSC and the interaction between the constituents is useful for the different analysis of the FPLSC. Graph theoretic approach is useful to represent the structure of the system which is further converted into useful form using matrix algebra [64-66].

A large numbers of FPLSC systems are available in the market of different companies which make the selection of optimal FPLSC system for the desired application difficult. The thermal efficiency is the very useful criteria for the selection of FPLSC system. But there are many other parameters are also important for the selection of FPLSC like reliability, quality, cost etc. There is no model found in literature for the selection of FPLSC considering the various parameters affecting the selection of FPLSC. So there is a need of the particular approach for the selection of the optimal FPLSC system from the given systems. Multi Attribute Decision Making (MADM) approach is useful in the selection of a system taking into consideration of multi criteria [62, 63]. The following objectives are proposed to fulfill the above requirement:

1. Development of mathematical model of the system using graph theoretic approach which integrates the different parameters and describe the system while taking into account the effect of interaction between these parameters.
    - A way to represent the FPLSC for the better understanding of the structure of FPLSC
    - Precise classification of different FPLSC systems
    - A model for the analysis of FPLSC from different prospective like quality, reliability etc.
2. A new procedure for the selection and evaluation of the different flat plate liquid solar collectors considering the factors affecting the selection using MADM approach.
    - Precise classification of FPLSC.
    - A new approach to make the selection of FPLSC systems easy.
    - A procedure for the evaluation of the selected systems to find out the optimal one.
    - Sensitivity analysis for the evaluation of more effective parameter for the selection of the system.

Literature papers are reviewed to see the effect of different environment, operating, design and material properties on the flat plate solar collector. Different applications of flat plate solar collector are also reviewed. Papers are reviewed on the MADM and graph theory approaches to see the usefulness, implementation criteria and procedure of implementation.

## 2.1 General literature review about FPLSC

Rama Subba Reddy Gorla [14]: Developed the 2D finite element model for the flat plate solar collector. The different Characteristics of the system are studied and compare with the experimental data for the validation of the model. The following parameters are evaluated for the validation of model.

- Fluid temperature increases along the length of the tube
- Fluid temperature varies linearly at high flow rates along the length of tube
- Fluid outlet temperature decreases with increase in mass flow rate
- Efficiency decreases with increase in fluid inlet temperature
- Efficiency higher with single cover for low inlet temperature range after some temperature efficiency of two glass cover higher than single
- Efficiency increases with increase in tube spacing to tube diameter ratio and after some point it decreases with further increase in tube spacing to tube diameter ratio.

Ho-Ming Yeh et al. [15]: Study the effect of aspect ratio (l/n·w) on collector performance. l is the length of the tube carrying fluid, n is the number of tubes and w is the spacing between the tubes. In this collector area is fixed and aspect ratio is varied by the variation in n and l. From the study it is concluded that efficiency increases with decrease in aspect ratio. It is also observed that efficiency decreases with increase in solar intensity when the inlet temperature is low and efficiency increases with increase in intensity when the inlet temperature is high.

H. Kazeminejad [16]: Studied the variation in results between the 1D model and 2D models for the FPLSC evaluation by applying different boundary conditions. FVM is used for solving of these equations. The following results are obtained after comparing the two models.

- Result obtained from the one dimensional Analysis is different from two dimensional Analysis at low mass flow rates.
- Fluid outlet temperature decreases with increase in mass flow rate and also increases with increase with distance between tubes.
- Fluid outlet temperature increases with increase in inlet temperature
- Fluid temperature increases along the tube.
- Efficiency increases with increase in mass flow rate
- Efficiency increases with increase in thermal conductivity of plate.
- Optimum performance at tilt 28.98 degree
- In this case efficiency decrease with increasing number of glass covers
- Efficiency decrease with increase in spacing between the tubes.
- Efficiency decrease with increase in temperature difference between inlet and outlet fluid temperature.

K. Sopian et al. [58]: A flat plate solar collector is fabricated from the thermoplastic natural rubber. Absorber plate and tube are made of thermoplastic natural rubber. The performance parameters of the collector are $F_R$ (τα) and $F_RU_L$ are .72 and 9.67. Thermo siphon solar water heater developed by this collector produce water outlet temperature to 65°C for the radiation level 500 W/$m^2$. There are two approaches used for the performance evaluation. In first case everyday fresh water is filled to take the readings. There is a temperature rise of 15°C for the energy input 4.5 kWh/$m^2$. In $2^{nd}$ method no water is withdrawn from the storage. There is an increase in water temperature of 60°C.

N.K. Vejen et al. [27]: Theoretical and experimental analysis of HT solar collector with different insulation materials, absorber, anti-reflecting coating and number of risers is carried out. There is a 23-37% output improvement using improved HT collector. Rock wool (low thermal conductivity) insulation gives better thermal performance than glass wool at temperature between 40°C-80°C. Efficiency improves with number of risers but only at low temperatures. Efficiency improve with improve in absorber properties for all temperatures. Effect increases with increase in temperature of the fluid. Efficiency improved with decrease in glass thickness.

I. Luminosu [17]: Study the relation of outlet temperature of heat carrying fluid with the parameters like efficiency, mass flow rate, collector area and specific heat of fluid for a given quantity of solar radiation. These parameter are combined into two variables $\alpha = A_c \eta$ and $\beta = mC_P$. Here $A_c$- represent collector area, η-represent the efficiency of the collector, m-represent the mass flow rate and $C_P$- specific heat value of fluid. Develop the model using Temp algorithm and compare the results with the experimental data, results are consistent with the experimental data.

A.A. Ghoneim [47]: Honeycomb materials are placed between the absorber and the cover to suppress the convective heat transfer. Evaluate the effect of different arrangements of honeycomb material, distance from the absorber and distance from the transparent cover on the top heat transfer experimentally. Honeycomb materials reduce top convection heat transfer but at the expense of poor optical performance so proper arrangement of honeycomb materials is required to improve the optical performance. Distance from the absorber plate is more effect the convective heat transfer than the distance from the transparent cover.

Subhra Das et al. [31]: Study the effect of various parameters on the performance of flat plate solar collector. These factors are characterized in fig.2.1

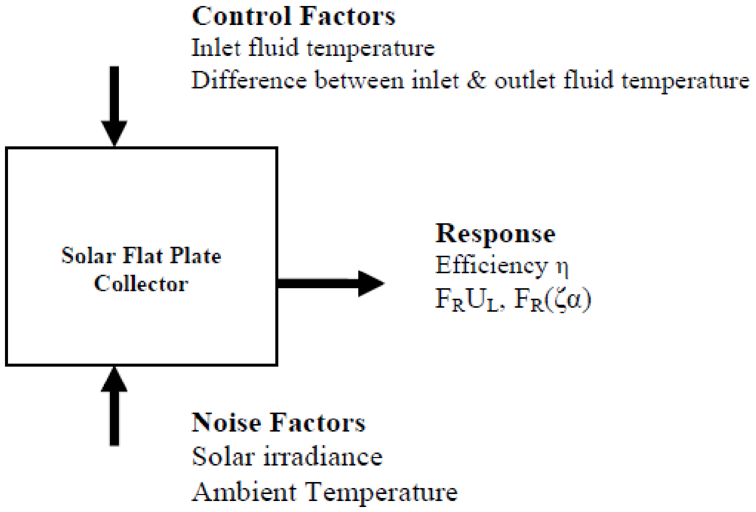


Fig 2.1 Factors effecting performance

This gives the tolerable limits for deviation to the input parameters for steady state conditions. Permissible deviation in collector fluid inlet temperature and temperature difference between collector inlet and outlet is $\pm .14^{o}C$.

Viorel Badescu [43]: Develop the optimal control of flow rate in case of open loop system for maximum exergy extraction. Trajectory optimization by mathematical programming (TOMP) is used for the optimal control. Evaluation of flow rate is done for both season's winter and summer. Optimal mass flow rate increases near sun rise and sun set. There is also in optimal mass flow rate with increase in inlet temperature.

Wei Sheng-Xian et al. [45]: Evaluate the area compensation ratio of solar collector integrated with the buildings to reduce the extra cost of installation. Cost of collector directly connected to the area of collector. This problem is rises due to roof azimuthal and tilted angles. Area compensation ratio is dependent on roof azimuthal, tilt angle, ambient temperature and horizontal solar radiation. Roof tilt angle $25^{o}$-$45^{o}$ and $|\text{azimuthal angle}| \leq 30^{o}$, the collector can intercept maximum radiation.

HuseyinGunerhanet et al. [46]: Fortan 90 computer program is developed to evaluate the optimum tilt angle of solar collectors for building applications. Experimental data measured in the Solar-Meteorological Station of Solar Energy Institute in Ege University over a 3-year period from 1994 to 1996were used to determine the optimum tilt angle for Turkey. The best orientation for Izmir is due south.

Adnan Soen et al. [36]: A new formula is developed on the basis of neural network approach to determine the efficiency of the flat plate solar collector. This approach is used for complex structures those are difficult to solve by other approaches. Surface temperature in collector, date, time, solar radiation, declination angle, azimuthal angle and tilt angles are used as input to the network for efficiency calculation. This model is fast, simple and capacity to learn from examples.

Alireza Hobbi et al. [29]: An experiment is performed to see the effect of heat enhancement devices on the collector performance. Four types of arrangement are analyzed regular circular tube, regular tube with twisted strip turbolator, regular tube with coil spring wire and regular tube with conical ridges installed in every 152mm. no significant effect on the performance of collector.

S. Farahat et al. [30]: Exergetic optimization is developed for the flat plate solar collector to improve and optimize the performance of the collector. Absorber plate area, dimension of solar collector pipes, diameter, mass flow rate, fluid inlet, outlet temperature, the overall loss coefficient are taken as variables. Exergetic efficiency increases with increase in fluid inlet temperature, decrease with increase in ambient temperature, increase with increase in pipe diameter, decrease with wind speed, increase with increase in optimal efficiency, increase with increase in incident energy.

Y. Raja Sekhar et al. [22]: An experiment is performed for to evaluate the top loss coefficient considering the aspects like insolation, emissivity of absorber, ambient temperature, wind loss coefficient, tilt. A theoretical investigation is also done. The following results are obtained:

- Efficiency decreases with increase in emissivity of the plate
- Efficiency increases with increase in ambient temperature
- With increase in wind loss coefficient Efficiency decreases
- No significance effect, due to tilt on top loss coefficient

C. Dorfling et al. [26]: Numerical modeling and experiment is performed on collector made of thermoplastic extrude. The extrude, termed as microcapillary film (MCF), consists of an extruded flexible, plastic, film with a parallel array of hollow capillaries running along the film's length. In this see the effects of different process fluids, glazing layers and collector backgrounds had on the overall heat recovery of the collector. The experiments also saw the effects that fluid flow rate, collector length and capillary wall thickness had on the output. A finite difference model was given to calculate the temperature gain and the output of these solar collectors as a function of design and operating parameters.

T.N. Anderson et al. [60]: Experimental and theoretical calculations are made to see the effect on the performance of building integrated flat plate solar collector using colored absorber at the place of black absorber. Thermal efficiency of grey color is higher than the other colors (green, red and white) but less than the black. After grey, green on the 2$^{nd}$ place and red at the third place. White collector is able to provide 25% of the heating load, so colored collectors have significant capability to fulfill water heating demand.

Naiem Akhtaret et al. [23]: See the effect of absorption of radiation in glass cover on the top loss coefficient for single and double glass cover. Temperature of the glass cover increased by 6ºC in case of single glazing. Temperatures of the glass covers are increased by 14ºC and 11ºC in case of double glazing. There is a difference of 49% in the value of convective heat transfer coefficient, with and without considering the absorption in glass cover in case of double glazing. The correlations are developed for to calculate the absorption effect in the glass cover.

Madhukeshwara et al. [24]: Study the effect of selective coating on the performance of the flat plate liquid solar collector. Three types of selective coatings are studied Black Chrome, Matt Black and Solchrome. Parameters those are studied to see the effect are efficiency, tilt and outlet water temperature. Different types of selective coatings are shown in table 2.1. Black chrome is better than the remaining coatings. Efficiency is highest at tilt of 30 degrees.

Table 2.1
Selective coatings optical properties

| Selective coatings | α | ε | α/ε |
|---|---|---|---|
| Black Chrome | .93 | .10 | 9.3 |
| Black Nickel on polished Nickel | .92 | .11 | 8.4 |
| Black Nickel on galvanized Iron | .89 | .12 | 7.4 |
| CuO on nickel | .81 | .17 | 4.7 |
| $Co_3O_4$ on silver | .90 | .27 | 3.3 |
| CuO on Aluminium | .93 | .11 | 8.5 |
| CuO on anodized Aluminum | .85 | .11 | 7.7 |
| Solchrome | .96 | .12 | 8.0 |
| Black paint | .96 | .88 | 1.09 |

P. Rhushi Prasad et al. [38]: An experiment is performed to investigate the influence of tracking on the performance of Flat plate solar collector of capacity 100 liters/day. There is increase in average outlet temperature by 4$^{o}$C using collector adjustment by 30 degree after every 2 hours and the efficiency improved by 21%.

Table 2.2
Glazing Materials

| Material | Transmittance (τ) |
|---|---|
| Crystal glass | 0.91 |
| Window glass | 0.85 |
| Polymethyl methacrylate (acrylic) (Acrylate, Lucite, Plexiglass) | 0.89 |
| Polycarbonate (Lexan, Merlon) | 0.84 |
| Polyethylene terephthalate (polyester) Mylar) | 0.84 |
| Polyvinyl fluoride (Tedlar) | 0.93 |
| Polyamide (Kapton) | 0.80 |
| Fluorinated ethylene propylene (FEP Teflon) | 0.96 |
| Fiberglass-reinforced polyester (Kalwall) | 0.87 |

Table 2.3
Optical properties of different surfaces

| Material | α | ρ | ε | α/ε |
|---|---|---|---|---|
| White plaster | 0.07 | 0.93 | 0.91 | 0.08 |
| Fresh snow | 0.13 | 0.87 | 0.82 | 0.16 |
| White paint | 0.20 | 0.80 | 0.91 | 0.22 |
| White enamel | 0.35 | 0.65 | 0.90 | 0.39 |
| Green paint | 0.50 | 0.50 | 0.90 | 0.56 |
| Red brick | 0.55 | 0.45 | 0.90 | 0.60 |
| Concrete | 0.60 | 0.40 | 0.92 | 0.68 |
| Grey paint | 0.75 | 0.25 | 0.88 | 0.79 |
| Black tar paper | 0.93 | 0.07 | 0.93 | 1.00 |
| Flat black paint | 0.96 | 0.04 | 0.88 | 1.09 |
| 3M Velvet black paint | 0.98 | 0.02 | 0.90 | 1.09 |
| Granite | 0.55 | 0.45 | 0.44 | 1.25 |
| Graphite | 0.78 | 0.22 | 0.41 | 1.90 |
| Aluminum foil | 0.15 | 0.85 | 0.05 | 3.00 |
| Galvanized steel | 0.65 | 0.35 | 0.13 | 5.00 |

M.K. Bhatt et al. [39]: An experiment is performed to evaluate the effect on heat losses of flat plate solar collector for different wind speeds. It is observed that maximum heat loss occur from the top, convective heat transfer increases with wind speed and the temperature of the collector reduces with increase in wind velocity.

M.S. Sodha et al. [61]: Study the rise in temperature of the solar collector and the insulation when the fluid flow stops. The three types of insulations (Asbestos, glass wool, polyurethane foam) are studied to see the effect on the temperature of the collector.

Table 2.4
Insulation material properties

| Case | Insulation | K w/m°C | P Kg/m³ | C kjm²°C | $U_L$ w/m²°C | $T_{PO}$ °C | $T_S$ °C | $T_{mt}$ °C | Δt sec |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Asbestos | .192 | 576.0 | .816 | 8.33 | 70 | 165 | 128 | 2000 |
| 2 | Glass-wool | .04 | 200.2 | .67 | 8.33 | 70 | 165 | 143 | 729 |
| 3 | Polyurethane foam | .023 | 32.04 | 1.21 | 7.14 | 70 | 185 | 170 | 1024 |

In case of polyurethane foam collector temperature increases very rapidly. After the stoppage of fluid flow for 20 minutes, the insulation is damaged because of its low service temperature. So there is a need of high service temperature insulation material for to safe the collector in case of fluid flow stoppage.

Tooraj Yousefi et al. [40]: An experiment is performed to study the effect of nanofluid on the efficiency of the flat plate solar collector. Another factors studied are nanofluid concentration, mass flow rate and surfactant on the efficiency of flat plate solar collector. Efficiency increases with mass flow rate, Efficiency increased by using nanofluids at the place of water, .2wt% nano-fluid has higher efficiency than .4wt% for large temperature difference range, Stability of low concentration solution is higher, Efficiency improves with surfactant(Triton X-100). There is 28.3% improvement in efficiency using nanofluid at the place of water. Surfactant improves the efficiency by 15.63%.

N. Ehrmann et al. [41]: A selectively coated double glazing flat plate solar collected is developed at Institute for Solar Energy Research Hamelin (ISFH). The purpose of this collector is to reduce the top heat losses and increase the transmittance of the collector. Fig2.2 shows the developed collector. Performance of this collector is evaluated by the simulations.

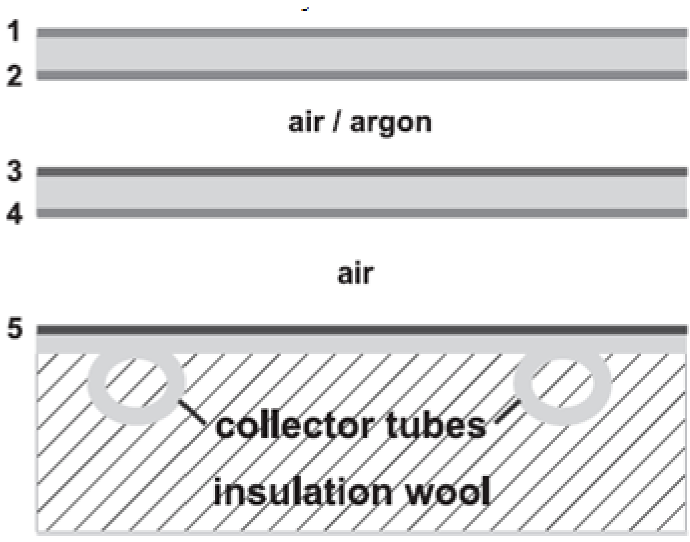


Fig 2.2 Double glazing flat plate solar collector

Here 1, 2, 4 are anti-reflecting coatings used to reduce the reflection losses. 3 is the low emittance transparent conductive oxide (TCO) coating reduce the radiation losses. Space between the covers filled with air or argon to reduce the heat losses. Transmittance of the developed collector is better than the only low emittance coated glass, single anti-reflecting coating and low emittance coating glass. Developed collector is more efficient than others.

M.C. Rodríguez-Hidalgo et al. [42]: Experiment is performed on the 9 year old 50 $m^2$ flat plate solar collector to evaluate the instantaneous efficiency of the collector. The initial performance evaluation done by the manufacture is only under limited values of operating parameters. But in actual collector has to face conditions different than the tested conditions. So a transient description of solar collector performance is necessary. The various parameters those effect the performance of the collector are study those are come with the time of use like surface aging. The various parameters effects the performance of the system are collector surface aging (15 % of the total output drop), wind velocity (15.7%), 3.2% due to thermal capacitance, incidence angle of radiation (7.6%).

Hamid Moghadam et al. [44]: Evaluate the optimum tilt angle for the flat plate solar collector to receive maximum solar radiation. A MATLAB program is developed to evaluate the optimum tilt angle on the day basis, month basis, annual basis or any specified time interval. The results are consistent with the experimental data.

## 2.2 Applications based literature review

### 2.2.1 Solar water heater

Flat plate solar collector is mostly used in solar water heaters because of its better performance for low temperature heating. The schematic diagram of solar water is shown in fig.2.3

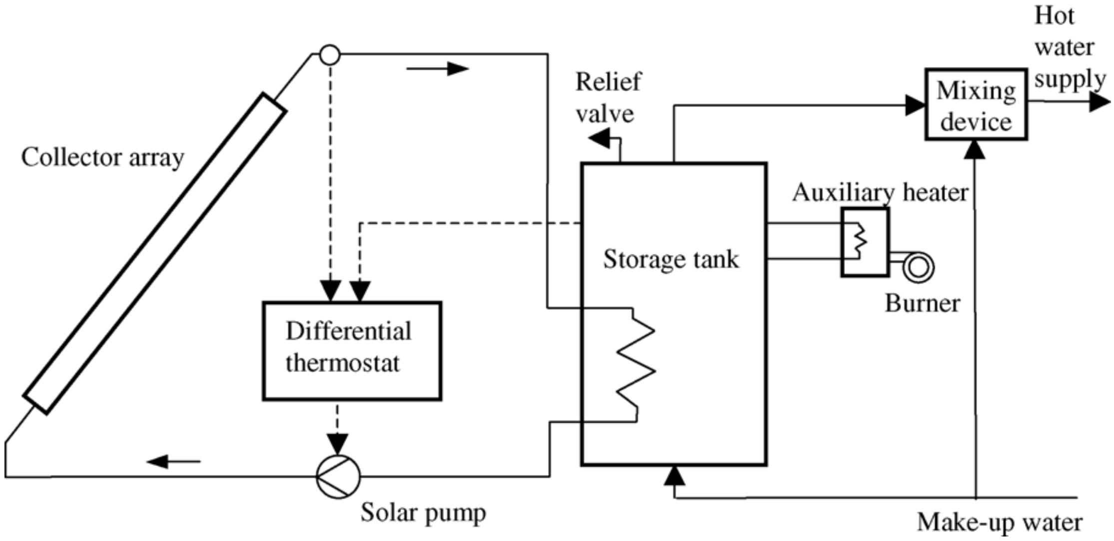


Fig 2.3 [25] Solar water heater

Ismail H Ozsabuncuoglu [51]: Economic analysis is done for the solar water heater, electric, wood, natural gas, lignite, coal and kerosene. The different type of costs are considered like material cost, transportation, cost, steel stand, connecting parts, pipe insulation, labor mounting the system, operational and maintenance cost. The effect of interest and inflation is also considered for the economic analysis of the solar water heater. Using present value criteria at the 20% interest rate solar water heater is preferable. But at the present interest rate of 60% in turkey solar water is not preferable. Using present value criteria taking into consideration of inflation, solar water heater is most preferable.

A. Manickavasagan et al. [20]: An experiment is performed for the effect of alternating fluid on the performance of FPLSC based solar water heater. Only acetone is used to see the performance of the solar water heater. Water is heated by the flow of alternative fluid from the heat exchanger. The desirable fluid properties for selection of fluid are given below:

i. Low boiling point
ii. High specific heat
iii. High latent heat
iv. Non corrosiveness to most of the fabrication materials
v. Wide useful range
vi. Easily available in market and low cost

vii. Excellent stability in working range
viii. Low freezing temperature
ix. Do not form scales in tubes
x. High thermal conductivity.

The various fluids used for the heat pipes are:

- Gases such as He,$N_2$
- Liquids such as water, methanol, ethanol, acetone, Freon, pentane, ammonia
- Metals such as mercury, potassium, calcium, lithium and silver.

Acetone used as a working fluid in the collector and the efficiency (energy gain by water by the solar irradiation) comes out 45%.

S. Kalogirou et al. [25]: Performance analysis of the colored absorber collector and black absorber collector is carried out. The results are compared with each other to see the effect of color on the performance of collector. Economic analysis is also done. This analysis is done for three types of applications like large water heating, Industrial process heating and space heating. There is a decrease of performance about 10% using colored absorber in case of large water heating system. Output of these coatings is 18% higher than ordinary coatings. In case of space heating difference between colored and black coating performance is about 13-18%. In case of industrial process heating difference between colored and black coating performance is about 9%.

K.P. Gertzos et al. [33]: An experiment is performed to analyze the flow field inside the integral collector storage system. A CFD model is also developed which is consistent with the experiment. This type of information is useful to know the possible sizing and arrangement of holding blades, diameter, length and placement of heat exchanger.

P.G. Loutzenhiser et al. [57]: Empirical validation is done of different models used for to calculate the solar radiation. Isotropic sky, Klucher, Hay–Davies, Reindl, Muneer, 1987 Perez, and 1990 Perez models are evaluated. Solar radiation data is collected for two different days and compared with the models. Global, direct and diffuse radiations are measured on a horizontal surface. The difference from the actual radiation data is 13.7% and 14.9% in case of Isotropic sky model. 9.1% for the Hay–Davies model, 9.4% for the Reindl model, 7.6% for the Muneer model, 13.2% for the Klucher model, 9.0%, 7.7%, 6.6%, and 7.1% for the 1990 Perez models and 7.9% for the 1987 Perez model.

K. Chung et al. [59]: An experiment is performed to evaluate the pressure distribution on the collector and the wind uplift force. There are two types of suggestions are evaluated to reduce the wind uplift: lift the model and guide plate. Wind speed used for the evaluation of wind uplift is in the range 20-50 m/sec. There is significant effect on wind uplift using guide plate normal to the wind. The effect of lifting the model is not much effective to reduce the wind uplift.

AhmetKoca et al. [55]: An experiment is performed to evaluate the exergy and energy performance of the integrated flat plate solar collector with phase changing material for thermal storage. Mobilterm 605 is used as a working fluid with thermal conductivity .145W/mK. PCM material used is $CaCl_2.6H_2O$. Energy and exergy efficiencies are 45% and 2.2%.

Katharina Resch et al. [56]: A review is done on the Thermotropic layers used for the overheating protection. Their transmittance is the function of the temperature of the collector. At higher temperatures transmittance reduces to decrease the collector temperature. Thermotropic hydrogels, thermotropic polymer blends and thermotropic systems with fixed domain are used for overheating protection.

YasinVarol et al. [54]: An experiment is performed to investigate the performance of a solar collector system using sodium carbonate decahydrate ($Na_2CO_3.10H_2O$) as Phase Change Material (PCM) during March. Collector efficiency was compared with those of convectional system including no PCM. Three different soft computing techniques as Artificial Neural Networks (ANN), Adaptive-Network-Based Fuzzy Inference System (ANFIS) and Support Vector Machines (SVM) used to predict the performance of the PCM based system. It was found that the solar collector system with PCM is more effective than convectional systems. Analysis of soft computing showed that SVM technique gives the best results.

K.P. Gertzoset et al. [48]: Study the effect of various parameters effect the outlet temperature of service water come from the heat exchanger immersed in the integrated collector storage using the Computational Fluid Dynamics. Factors considered for the optimization of the outlet temperature are placement of heat exchanger, tube length and tube diameter. Water in the collector is agitated by recirculation through the pump for better heat transfer. The optimal position was found to lay the HX in contact with the front and back walls of the tank, with an optimum inner tube diameter of 16 mm, while an acceptable HX length was found to be about 21.5 m.

L.M. Ayompe et al. [49]: A TRNSYS model is developed for the performance evaluation and other parameter calculations like outlet temperature in case of forced flow for flat plate and evacuated tube collector. The model is validated with the experimental data for systems installed in Dublin, Ireland. Results obtained showed that the model predicted the collector outlet fluid temperature with percentage mean absolute error (PMAE) of 16.9% and 18.4% for the FPC and ETC systems respectively. Heat collected and delivered to the loadwas also predicted with PMAE of 14.1% and 6.9% for the FPC system and 16.9% and 7.6% for the ETC system respectively. The model underestimated the collector outlet fluid temperature by -9.6% and overestimated the heat collected and heat delivered to load by 7.6% and 6.9% for the FPC system. The model overestimated all three parameters by 13.7%, 12.4% and 7.6% for the ETC system.

Yin Hang et al. [53]: Evaluate the performance of solar water heaters in United States for residential applications taking into consideration of different prospective economic, energetic and environment. There are two types of collectors are studied flat plate solar collector and evacuated tube collector. Two types of auxiliary systems are considered natural gas and electricity. Comparison is done between the performances of conventional water heater system with the solar water heater. This performance evaluation is done for three different locations. Flat plate solar collector with natural gas auxiliary heater has the best performance for all locations. Energetic and environment pay back periods for solar water heater is less than a year. Life cycle cost payback is varied from 4 to 13 years for different locations and different configuration.

### 2.2.2 Solar still

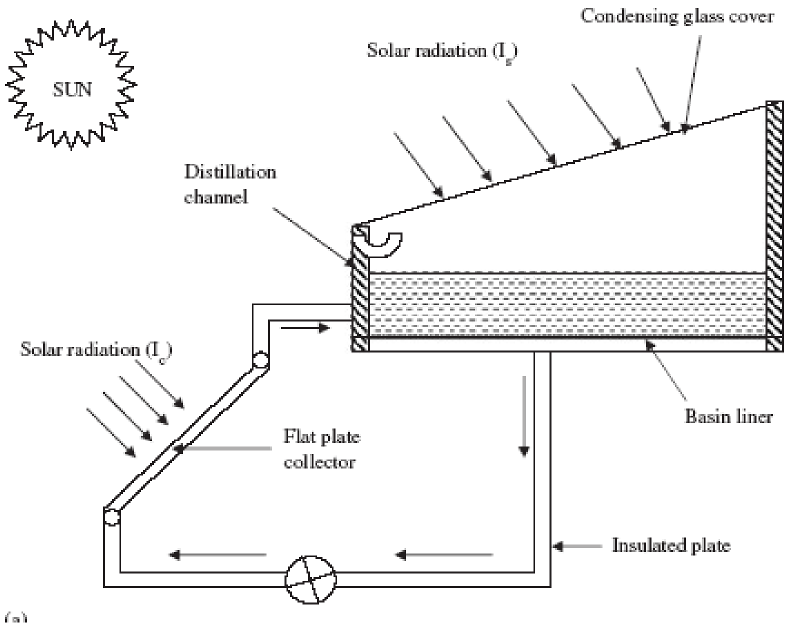


Fig 2.4 [50] FPLSC assisted solar still

Ali A.Badran et al. [32]: An experiment is performed to see the performance improvement of solar still by connecting a solar collector to flat plate collector. A single-stage, basin type solar still is used. Tap and saline water are used for to evaluate the performance. Different modes of operation still alone for 24 hours, still with flat plate collector for 24 hours and still connected only for sunshine hours. Tap water production is increased by 231% and saline water production increased by 52% using flat plate collector.

O.O.Badran et al. [19] an experiment is performed for to evaluate the effect of FPLSC on the performance of the solar still. The effect of different operating parameters is also studied on the performance of solar still. The operating parameters those are studied ambient temperature, water depth in solar still basin, solar still direction, water temperature in still and solar irradiation. The following results are obtained:

- By employing the flat plate collector productivity of solar still increased by 36%.
- Water output increases with increase in solar intensity.
- Increase in ambient temperature water production increases.
- Water output decreases with increase in water depth
- Water output increases with increase in basin water temperature.

Hitesh N. Panchal et al. [50]: An experiment is performed to evaluate the performance difference between the passive solar still and the solar still coupled with the flat plate solar collector. The other factors considered to see the influence on the performance of the solar still are water depth and solar irradiation. Water output increases with decrease in the water depth in the solar still and with increase in solar irradiation. There is 35% increase in water production with flat plate collector.

### 2.2.3 Effluent evaporation system

K. Srithar et al. [18]: An experiment is conducted to see the effectiveness of the FPLSC for the tannery effluent treatment. The evaporation rate of water from the effluent is increased by the following methods.

- Heating the effluent.
- Increasing the exposure area.
- Increasing the wind speed.
- Increasing the air temperature.
- Reducing the humidity of air.

First method is used by the author for effluent treatment. For the heating of tannery effluent, FPLSC is used. The different factors are studied those are effecting the effluent evaporation rate. The parameters those are investigated: Insolation, wind speed, relative humidity, mass flow rate and effluent concentration. The following results are obtained. The evaporation rate of water in the effluent increases

Due to increase in

- Insolation
- Wind speed

Due to decrease in

- Relative humidity
- Mass flow rate
- Effluent concentration.

### 2.2.4 Solar Cooker

O.A. Ogunwole [34]: A solar cooker is designed, fabricated and tested. Aluminum foils are used as reflectors to increase the input solar radiations. The temperature approaches to 100ºC at the ambient temperature of 34ºC.

### 2.2.5 Solar geyser cum distiller

S.H. Sengar et al. [35]: Develop a combined system for distillation and hot water. Performance analysis of the system is done taking into consideration inlet temperature, ambient temperature and solar irradiation. The output parameters studied are amount of water produced, efficiency. Efficiency in winter is 36.7% and in summer 27.48%. [35]

### 2.2.5 Solar Oven

Segun R.Bello et al. [37]: A solar oven is developed using flat plate liquid solar collector. Performance of the system is analyzed at different flow rates, tilt and solar irradiation. Efficiency of the flat plate solar collector is 51.82% and the overall system is 25.24%. Optimal flow rate calculated is .25 l/min. [37]

### 2.2.6 Solar heat pump

A. Georgiev [52]: Performance evaluation of heat pump is operated by the heat taken from the flat plate solar collector. Heat collected by the collector is used in the evaporator of the heat pumps as a heat source. The exhaust of the heat pump is further used for water heating. The parameters considered for the performance evaluation of the system are the medium fluid condenser temperature, the fluid condenser mass flow rate and medium fluid evaporator temperature. The COP of heat pump and efficiency of the system are evaluated. Efficiency increase with decrease in condenser temperature, increase of condenser mass flow rate and increase in evaporator temperature.

### 2.2.7 Solar cooling system

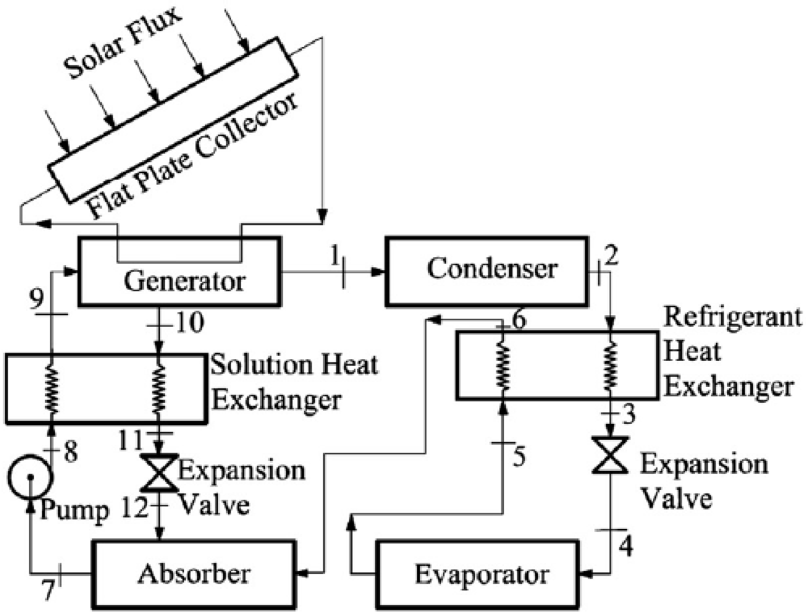


Fig 2.5 [28] Solar cooling system

B. Kundu et al. [28]: Study the effect of different absorber profiles (rectangular, convex parabolic, trapezoidal, triangular, concave parabolic) on the performance of the solar-powered vapor absorption cooling system. Performance of the collector studied for different fluid inlet temperatures. A simulation is developed for to do this. Rectangular fin is more efficient than other fins. Collector efficiency and heat removal factor are higher for rectangular fin.

### 2.2.8 Combined solar water heating and space heating

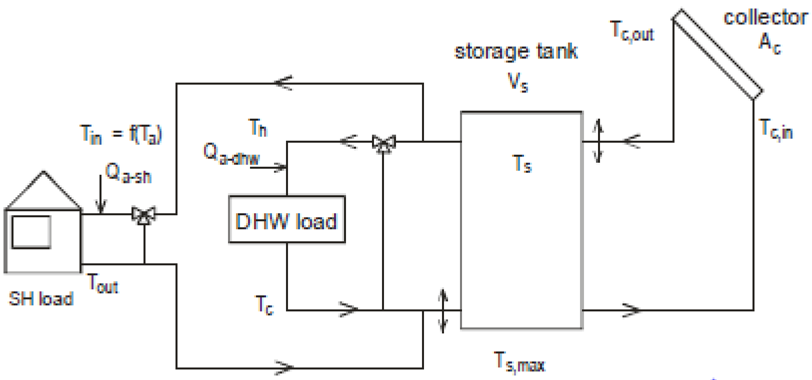


Fig 2.6 [21] Combined water and space heating system

J. Metzger et al. [21]: A simulation analysis is performed for the following Purposes using TRNSYS and TRNFLOW softwares.

- Study of combined systems (space heating and water heating)
- See the effect on the performance on the collector and the building load conditions by using direct integration and indirect integration to the wall.

The following results are obtained:

- Space heating demand decreases by direct integration.
- Space cooling demand increases by direct integration.
- Evacuated more efficient than atmospheric collector.

## 2.3 Literature review of system approaches

P.P. Bhangale et al. [63]: A large number of parameters are considered for the selection of the robot. Robots are characterized in terms of its attributes. With the help of these different robots are specified more precisely in terms of attributes. Further these attributes are used for the selection and evaluation of the robots for different applications using MADM approach.

K. Suresh Babu et al. [62]: Multi attribute decision making approach is used for the selection of materials for the wind turbine blades. Selection of material depends on many parameters low cost, high stiffness, low density and long fatigue life. Attributes are collected relating to the wind turbine blade material. A finite number of attributes are shortlisted for the selection of blade material. Technique for order preference by similarity to ideal solution (TOPSIS) is used for the selection of blade material. This gives the solution nearer to the ideal best one and farthest from the negative ideal solution. Different methods for MADM approach are Weighted Sum, Lexicographic, AHP, SMART, TOPSIS, ELECTRE, PROMETHEE, Goal Programming etc. different methods give different results. There is a need of great knowledge of decision makers about the alternatives and their preference weights.

C.Phaneendra Kiran et al. [64]: In this model is developed for the concurrent engineering design of the mechatronic system using graph theoretic approach. There are number of parameters those are considered for the design of mechatronic system is identified and then the interactions between these parameters are identified. A graph is constructed to show the different parameters and the interaction between the parameters. The graphical information is converted into matrix form for to make it more useful. Further permanent function is developed which is useful for the evaluation of the system. This permanent function is flexible with the numerical values of the parameters and useful to drive different results.

R.T. Durai Prabhakaran et al [65]: Identify the different processes, parameters drive the composite product properties and the interaction between these parameters. Develop a graph shows the various processes and the interaction between these processes. Similar to the above paper matrix and permanent function are developed for the composite product.

Varinder Singh et al [66]: Structure modeling of manufacturing systems is developed using graph theoretic approach. The different manufacturing systems and the interaction between these are identified. Develop the graph between the manufacturing systems and the interaction between the systems. This information from the graph is converted into matrix form which is used for the development of permanent function.

## 2.4 Limitation of present Literature review and today need

Literature review is the way to get the information from the data available in the form of research papers on the particular research field. Knowledge is extracted from the information to reach the concluding point or gap on which further research has to be carried out. Literature review requires to represents the history of the particular research field, what is being done in that field, what is going in that field, what are the basic parameters (attributes) of the field etc.

In [13] the review is done on the materials used for FPLSC. [14] represents the literature review related to the type of methods used to calculate the heat losses from FLPSC and then represent a new two dimensional methodology to evaluate FPLSC performance. [15] represent the literature review on the design of absorber plate and risers arrangement for efficiency improvement and then vary the aspect ratio to see the effect by keeping absorber area constant. [16] represent the literature review related to different two dimension models used to evaluate the FPLSC with different boundary conditions. [18] shows various ways to treat tannery effluent and their limitations, then propose a solar collector assisted heating system for effluent evaporation. [19] review the various design of solar still to improve the water productivity of still, propose a solar collector assisted solar still and see performance with different operating parameters. It is clear that in different research papers the literature review is done as per their particular issue of interest. The above type of literature review is not able to give complete information about the history and present state of the research field to anyone who wants to do research in that area. If the information of literature review of research papers collect together at single place so that a database is formed which give information about all the issues and attributes related to the FPLSC. Books are good for historical information about the research field but not capable of to represent the present state of the field which is developing day by day. There is a need of database which represents complete information about the research field and has the ability to update with the present state of research. Then this is very useful for any researcher in that particular field to get the useful information about any issue of interest which is useful to get the gap for further research. This database become more useful and informative as it is updated with new research papers. To reach above goal a new methodology is proposed.

In this study a new methodology is proposed to collect the complete information about the research field in terms of its attributes and make a permanent database of knowledge about that field. This information is collected from the research papers available on that field. This type of information is very useful for new researcher, manufacturers and the industrialists. This methodology is applied on FPLSC and show the type of information develops from the matrix.

## 2.5 Methodology

### 2.5.1 Characterization of paper:

Any research paper describes one or more parameters of the research field to see the desired output. So every research paper characterize by research field parameters as shown below:

$$P_j = \left\{ A_1, A_2, A_3, - - - \ Ai, --- A_m \right\}$$

Here $P_j$ represents the $j^{th}$ research paper and $A_i$ represents the $i^{th}$ attribute and I = 1, 2, 3 - - - - m. Where m represents the total number of parameters relating to the research field, those are found from the literature papers.

### 2.5.2 Identification of attributes

It is necessary to find out attributes for the characterization of the paper. These attributes are collected from the research papers and the data available in the books on that field.

### 2.5.3 Coding scheme

These attributes are qualitative in nature so for to get depth of information available in different research papers about these attributes convert them into quantifiable form by numbering it to the interval scale of 0-5 as shown in table 2.5 by the team of experts.

Table 2.5
Quantification of attributes

| Amount of work | Code |
|---|---|
| Very high | 5 |
| High | 4 |
| Average | 3 |
| Low | 2 |
| Very low | 1 |

| | |
|---|---|
| No | 0 |

Each attribute replaced by a numerical value between 0-5 in the paper characterization to give the information about the amount of work done on attribute in the paper as shown below:

$P_j = \{ A_1, A_2, A_3, - - - - \; Ai,--- A_m \}$

Here $0 \leq (A_1, A2, A3, - - - A_i, - - A_m) \leq 5$

**2.5.4 Matrix formation**

The attributes are become quantifiable. The total work done on each attribute by different papers is obtained easily by simply adding the numerical value occupied by this attribute in the papers. The total work done in particular paper is also obtained by adding numerical values occupied by attributes present in the paper. This type of information tell the history of the attributes that on which attribute most research work is done and on which attribute less research work is done. This type of information is represented and handled most easily and efficiently in the form of matrix m*n, where m be the total number of attributes and n be the total number of papers as shown in fig.2.7

| PAPER / ATTRIBUTE | $P_1$ | $P_2$ | – | – | $P_j$ | – | – | $P_n$ | SUM |
|---|---|---|---|---|---|---|---|---|---|
| $A_1$ | | | | | | | | | $\sum_1^n a_{1j}$ |
| $A_2$ | | | | | | | | | $\sum_1^n a_{2j}$ |
| – | | | | | | | | | – |
| – | | | | | | | | | – |
| – | | | | | | | | | – |
| $A_i$ | | | | | $a_{ij}$ | | | | $\sum_1^n a_{ij}$ |
| – | | | | | | | | | – |
| – | | | | | | | | | – |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| $A_m$ | | | | | | | | | $\sum_1^n a_{mj}$ |
| SUM | $\sum_1^m a_{i1}$ | $\sum_1^m a_{i2}$ | – | – | $\sum_1^m a_{ij}$ | – | – | $\sum_1^m a_{in}$ | |

Fig.2.7 Information matrix

Columns represent the paper on the desired area of research and the rows represent the attributes finding from these papers. Attributes are the variables that related to the design, application, performance and other behavior of the system.

### 2.5.4.1 Knowledge from the matrix

It is very useful if this matrix is made on the excel sheet. The different options and tools in the excel software helps in gathering information in less time from the information matrix. The following knowledge is extracted from the information matrix using excel software.

- These sigma forms as shown in fig.2.7 give knowledge about the amount of work done on each attribute and the total research work done in particular paper. Each row total gives the total amount of research work done on that attribute till yet and each column total give total amount of research work done in that particular paper.
- Further ranking of the papers also done on the basis of total work done in the paper.
- Sorting used to get the information more quickly about the attributes on those maximum works is done in the papers and the attributes on those very less work is done. From the above information researcher get an idea about the attributes those are less exploited yet. This helps the researcher to narrow down the area of research field for to find gap point to do further research. Also the information about the attributes on those more work is done, gives the idea that these attributes are more important from the researcher point of view.
- Rearrangement of papers done easily to club the papers on the basis of same attribute of research so that it is easy to find the papers on particular attributes.
- Type of output parameters that are used by the researcher to evaluate the collector.
- Attributes can be clubbed together into some small number of groups in case of large number of attributes. So that particular attribute find easily.
- Number of attributes studied till yet in particular research field collects together on a single matrix.
- Information about the change in attribute of interest about a research field with time.

- It give information about the type of studied goes on in the collector field like theoretical models, experimental, software used to evaluate the collector.
- It helps in find the papers on the basis of type of work like theoretical, experimental, simulation.
- Spider Graph

  There are many papers those concentrate on same attributes, so to know which paper is more useful for the researcher, this IM is very useful. As the characterization of the each paper in terms of attributes represented in the IM on which spider graph is easily applied to get the more useful paper. Here the following example illustrates this:

  Suppose there are five parameters of researcher's interest studied in three papers those are presented in IM from which table 2.6 is sorted out.

Table 2.6
Paper characterization with different parameters

| Paper / parameter | Paper 1 | Paper 2 | Paper 3 |
|---|---|---|---|
| Parameter 1 | 5 | 2 | 4 |
| Parameter 2 | 2 | 5 | 3 |
| Parameter 3 | 4 | 3 | 4 |
| Parameter 4 | 3 | 1 | 1 |
| Parameter 5 | 3 | 5 | 5 |

A spider graph develops between these papers vs. parameters as shown in Fig.2.8 which make it easy to compare the research papers.

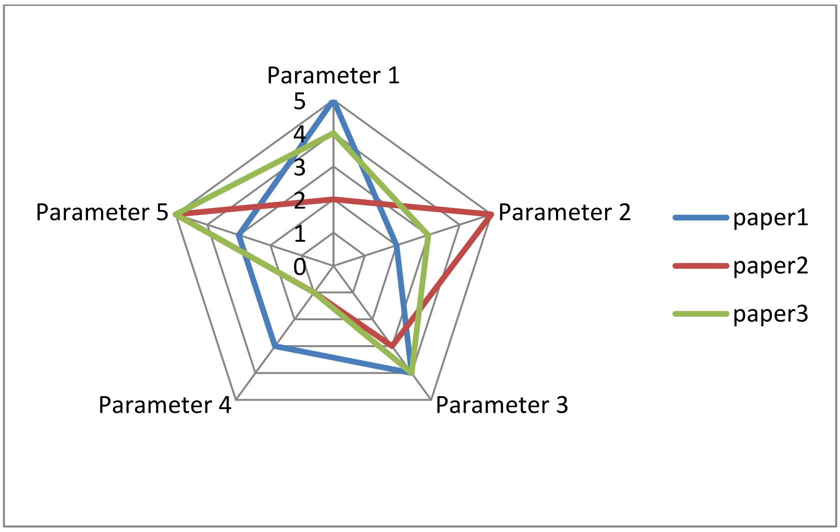


Fig.2.8 Spider graph

Spider graph forms from the above data. Each paper represent by a different color line. Five corners represent the five parameters. From the graph it is clear that paper 1 is best as per the 1st and 4th parameters. Paper 1st and paper 3rd are best as per 3rd parameter. Paper 2nd best for 2nd parameter and papers 2nd and 3rd are best for 5th parameter. Area enclosed by each color line gives the total amount of work done.

- In IM large number of attributes are collected on which researchers do work. So this gives the information about what is done in the research field. To get the gap, information required is the actual number of Attributes relating to research field. Cause and effect diagram develops as shown in fig.2.9, which represents graphically the different causes (attributes) those effect research field.

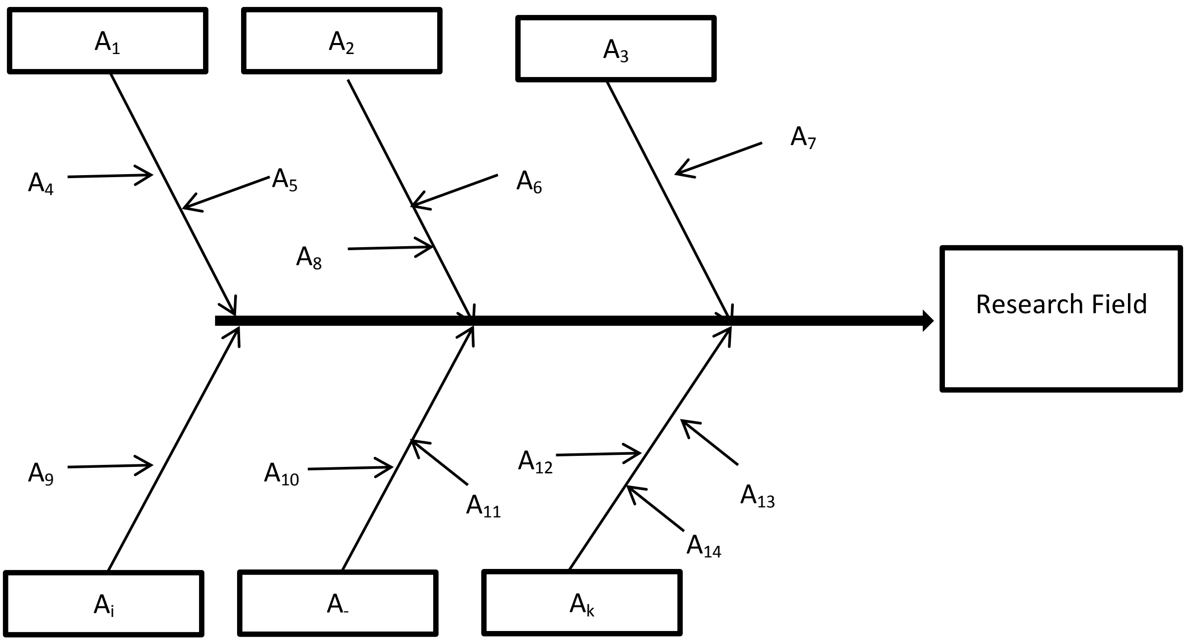


Fig.2.9 Cause and Effect diagram

$A_1$, $A_2$, $A_{3,}$ - - - - -$A_i$ - - - - - $A_k$ be the attributes. Gap points are found from the information get from IM and cause and effect diagram. Attributes which are present in cause and effect diagram but not present in IM are the attributes which are not studied yet.

2.5.4.2 Excel tools those helps in drive information from the information matrix.

- Auto sum is used for the summation of the different cells.
- Different types of sorting are used to get the information from the information matrix are shown in fig.2.10.

| • General Form | Case 1 | Case 2 | Case 3 | Case 4 |
|---|---|---|---|---|
| **Special change in matrix** | No | No | Add an attribute of time of publication in the matrix | No |
| **Selection area** | IM without attribute list | Matrix without attribute list + Row of column totals | IM without attribute list | IM without paper list row + column of row total |
| **Sort & filter** | | | | |
| **Custom short** | | | | |
| **Options** | | | | |
| **Orientation** | Left to right | Left to right | Left to right | Top to bottom |
| **Sort by** | Particular attribute row | Row of column total | Row of time of publication attribute | Column of row total |
| **Sort on** | Value | Value | Value | Value |
| **Order** | Largest to small | Largest to small | Smallest to large | Largest to small |

Fig.2.10 Steps for sorting in Excel

Case 1 – sorting of papers on the basis of attribute presence
Case 2 – Sorting of papers on the basis of amount of work done
Case 3 – Sorting of papers as per the time of publication
Case 4 – Sorting of attributes on the basis of amount of work done

### 2.5.4.3 Characteristics of IM:

Matrix is easily stored in the computers in the form of excel sheet. This become a permanent source of knowledge and usable any time. It is flexible to addition of the new research paper as there is just a new column created in the matrix corresponding to that paper so someone update IM as per their requirements by adding the papers of his interest, also the IM become more informative as the number of papers increases. It is flexible to the addition of new attribute as it creates a new row corresponding to the attribute in the IM.

2.5.5 Implementation of methodology on FPLSC

2.5.5.1 Characterization of research papers

Characterization of papers on FPLSC are done as per section 2.1

2.5.5.2 Identification of attributes

Attributes are large in number so attributes are categorized as below for better handling of attributes:

I. Input attributes

   Attributes which are used for to evaluate the FPLSC collector.

   These are divided further:

i. General attributes

   Attributes related only to the FPLSC designing

   These are further divided as:

   a. Absorber plate
   b. Transparent cover
   c. Tubes

ii. Operational attributes:

   Attributes used to operate the system like mass flow rate, tilt, inlet temperature of fluid etc.

iii. Environment attributes:

   Attributes like ambient temperature, wind velocity comes under this category.

iv. Others

   Other than above general attributes are goes to this category.

v. Application based

   Attributes related to the system in which solar collector is a component of the system. Examples are; solar still, solar water heater, solar oven, solar cooling etc.

II. Type of work

   For to give the information about the type of work done by the researcher to study the system, this also becomes an attribute which is further categorized below:

i. Simulation

   Software used to simulate the FPLSC performance and other factors.

ii. Theoretical

There are many theoretical approaches used to evaluate the collector so for to collect these approaches type of approach is also used as attribute.

iii. Experimental

a. Instruments

Different instruments are used for to measure the different system properties in the experiments. To collect the information about these instruments they are also used as attribute.

III. Output attributes

Attributes related to the outputs that are studied correspond to the FPLSC and its applications.

**2.5.5.2.1 Literature review in terms of attributes**

Format to write the information

Author

Type of work

Type of system

Attributes

Instruments

1. Rama Subba Reddy Gorla [14]

   Theoretical (2D finite element model)

   Attributes:

   i. Flow rate
   ii. Fluid outlet temperature
   iii. Fluid inlet temperature
   iv. Efficiency
   v. Number of glass cover
   vi. Tube diameter
   vii. Tube spacing

2. Ho-Ming Yeh et al. [15]

   Theoretical

   Attributes:

   i. Length of tube

ii. Number of tubes
iii. Spacing between tubes
iv. Inlet temperature
v. efficiency

3. H. Kazeminejad [16]

   Theoretical (Finite Volume Method)

   Attributes:

   i. Mass flow rate
   ii. Two. Dim. Model
   iii. Spacing b/w tubes
   iv. Inlet temperature
   v. Outlet temperature
   vi. Outlet and inlet Temperature difference
   vii. Inlet and ambient temperature difference
   viii. Absorber plate mean temperature
   ix. Fluid temperature variation along the tube.
   x. Efficiency
   xi. Thermal conductivity of absorber plate
   xii. Tilt
   xiii. Number of glass cover

4. I. Luminosu [17]

   Theoretical (Temp)

   Experimental

   Attributes:

   i. Collector area
   ii. Efficiency
   iii. Mass flow rate
   iv. Specific heat
   v. Solar irradiation
   vi. Fluid outlet temperature

5. K. Srithar et al. [18]

Theoretical

Experimental

Attributes:

i. Concentration of effluent
ii. Mass flow rate
iii. Solar irradiation
iv. Evaporation rate
v. Relative humidity
vi. Wind speed

6. O.O.Badran et al. [19]

Experimental

Attributes:

i. Ambient temperature
ii. Amt. of Water produced
iii. Water depth
iv. Tilt
v. Water temperature of still

Instruments:

i. Thermo couples

7. A. Manickavasagan et al. [20]

Experimental

Solar water heater

Attributes:

i. Working fluid
ii. Efficiency
iii. Solar irradiation
iv. Plate temperature
v. Inlet temperature
vi. Glass plate temperature

Instruments:

i. Surya mapi
ii. Mercury thermometer
iii. Thermocouples

8. J. Metzger et al. [21]
Simulation
Attributes:
i. Fixing or non-fixing to the wall.
ii. Vacuum or non-vacuum collector.
iii. Collector area.
iv. Solar fraction
v. Ambient temperature
vi. Solar irradiation

9. Y. Raja Sekhar et al. [22]
Experimental
Theoretical
Attributes:
i. Emissivity of plate
ii. Ambient temperature
iii. Top loss coefficient
iv. Tilt
v. Efficiency

10. Naiem Akhtar et al. [23]
Theoretical
Attributes:
i. Wind load
ii. Number of glass covers
iii. Upper face convective heat transfer coefficient
iv. Upper face radiative heat transfer coefficient
v. 1$^{st}$ glass cover inner temperature
vi. 1$^{st}$ glass cover outer temperature
vii. 2$^{nd}$ glass cover inner temperature

viii. 2nd glass cover outer temperature

ix. Emissivity of absorber plate

x. Absorber plate temperature

xi. Absorption in glass cover

11. Madhukeshwara et al. [24]

Experimental

Attributes:

i. Selective coating

ii. Efficiency

iii. Tilt

iv. Solar radiation

v. Outlet water temperature

Instruments:

i. Thrmometres

12. S. Kalogirou et al. [25]

TRNSYS

Solar water heater (separate + indirect)

Attributes:

i. Location

ii. Useful energy

iii. Auxiliary energy

iv. Months

v. Solar irradiance

vi. Absorber color

vii. Application (space heating, water heating and industrial water heating)

13. C. Dorfling et al. [26]

Theoretical (FDM)

Experimental

Attributes:

i. Type of absorber

ii. Absorber material

iii. Insulation material
iv. Flow rate
v. Micro capillary film voidage
vi. Heat recovery (output)
vii. Type of fluid
viii. Color of absorber
ix. Temperature increase
x. Collector length
xi. Glazing material
xii. Glazing thickness
xiii. Pressure drop

14. N.K. Vejen et al. [27]

Theoretical

Experimental

Attributes:

i. Efficiency
ii. Thermal performance
iii. Insulation material
iv. Type of Absorber
v. Number of risers
vi. Anti-reflection treated Glass cover
vii. Cost
viii. Temperature difference b/w absorber plate & ambient temperature
ix. Absorber plate temperature

15. B. Kundu et al. [28]

Theoretical

Attributes:

- Fluid inlet temperature
- Collector efficiency
- Cycle efficiency
- Different absorber shape

- Heat removal factor
- Instantaneous efficiency
- COP
- Efficiency

16. Alireza Hobbi et al. [29]

    Experimental

    Attributes:

    i. Heat enhancement devices
    ii. Temperature difference
    iii. Mass flow rate
    iv. Solar irradiation

    Instruments:

    i. Thermo couple
    ii. Rota meter
    iii. Data acquisition system

17. S. Farahat et al. [30]

    Theoretical

    Simulation

    Attributes:

    i. Exergetic efficiency
    ii. Fluid inlet temperature
    iii. Ambient temperature
    iv. Diameter of pipes
    v. Wind speed
    vi. [Optical efficiency
    vii. Solar irradiation

18. Subhra Das et al. [31]

    Experimental

    Theoretical

    Attributes:

i. Inlet fluid temperature
ii. Ambient temperature
iii. Deviation in inlet fluid temperature
iv. Solar irradiation
v. Efficiency
vi. Acceptable deviation in inlet fluid temperature
vii. Acceptable deviation in Inlet and outlet temperature difference

19. Ali A. Badran et al. [32]

Solar still

Experimental

Attributes:

- Ambient temperature
- Amount of water produced
- Solar irradiation

20. K.P. Gertzos et al. [33]

Experimental

Theoretical

Attributes:

i. Flow path
ii. Velocity distribution
iii. Temperature of tank
iv. Temperature of service outlet water
v. Recirculation
vi. Time

Instruments:

i. Buoyancy meter (recirculation flow rate)

21. O.A. Ogunwole [34]

Theoretical

Experimental

Attributes:

i. Solar irradiation
ii. Ambient temperatue
iii. Temperature of absorber

22. S.H. Sengar et al. [35]

Experimental

Attributes:

i. Inlet temperature
ii. Amt. Of water produced
iii. Inlet temperature
iv. Outlet temperature
v. Ambient temperature
vi. Efficiency
vii. Solar radiation
viii. Ambient temperature

Instruments:

i. Insolometer
ii. Thermocouple

23. Adnan Sozen et al. [36]

Theoretical

Attributes:

- Tilt
- Efficiency
- Azimuthal angle
- Declination angle
- Date
- Time
- Solar radiation
- Absorber temp

24. Segun R.Bello et al. [37]

Experimental

Attributes:

i. Tilt
ii. Overall Efficiency
iii. Flow rate
iv. Solar radiation
v. Absorber temperature

Instruments:

i. Thermometers

25. P. Rhushi Prasad et al. [38]

Experimental

Attributes:

i. Outlet temperature
ii. Tracking
iii. Efficiency

26. M.K. Bhatt et al [39]

Experiment

Attributes:

i. Top heat loss
ii. Bottom heat loss
iii. Edge heat loss
iv. Sealing heat loss
v. Wind velocity
vi. Solar irradiance

27. Tooraj Yousefi et al. [40]

Experimental

Attributes:

i. Mass flow rate
ii. Efficiency

iii. Ambient temperature
iv. Inlet temperature
v. Outlet temperature
vi. Solar irradiation
vii. Nano particle concentration
viii. Type of fluid(nano particle + surfactant effect)

28. N. Ehrmann et al. [41]

Experimental

Attributes:

i. Selective AR coating for glass cover
ii. Solar irradiation
iii. Transmittance
iv. reflectance
v. Efficiency

29. M.C. Rodríguez-Hidalgo et al. [42]

Experimental

Attributes:

i. Wind velocity
ii. Collector aging
iii. Thermal capacitance
iv. Radiation loss
v. Irradiance incidence angle
vi. $Q_{out}$
vii. $T_{out}$

30. Viorel Badescu [43]

TOMP algorithm theoretical

Attributes:

i. Exergetic efficiency
ii. Mass flow rate
iii. Day time
iv. Solar irradiation

v. Fluid inlet temperature

31. Hamid Moghadam et al. [44]
   Theoretical mathematical model
   MATLAB (simulation)
   Attributes:
   i. Tilt angle
   ii. Declination angle
   iii. Latitude
   iv. Degree of surface inclination
   v. Hour angle

32. Wei Sheng-Xian et al. [45]
   Theoretical
   Integrated collector
   Attributes:
   i. Roof Azimuthal angle
   ii. Roof Tilt angle
   iii. Collector area ratio

33. Huseyin Gunerhan et al. [46]
   Theoretical
   Attributes:
   i. latitude
   ii. Optimum tilt
   iii. Day of the year
   iv. Extraterrestrial radiation

34. A.A. Ghoneim [47]
   Experimental
   Theoretical (regression analysis)
   Attributes:
   i. Space condition b/w absorber and glass cover
   ii. Different arrangements of Honey comb material

iii. Distance b/w absorber plate & honey comb material
iv. Distance b/w glass & honey comb material
v. Nusslet no.
vi. Rayleigh no.
vii. Efficiency
viii. Difference in temperatures o plate & ambient air

Instruments:

i. Pyranometer
ii. Flow meter
iii. Anemometer

35. K.P. Gertzos et al. [48]

Simulation

Experimental

Attributes:

i. Heat exchanger tube diameter
ii. Distance from the tank walls
iii. Length of heat exchanger
iv. Service Water outlet temperature
v. Service water flow rate

36. L.M. Ayompe et al.[49]

Simulation

Experimental

Attributes:

i. Model validation
ii. Useful energy collected
iii. Outlet temperature
iv. Flow rate
v. Solar radiation
vi. Wind speed
vii. Ambient air temperature

37. Hitesh N. Panchal et al. [50]

Experimental

Attributes:

i. Solar intensity
ii. Water output
iii. Output with & without collector
iv. Water depth

Measurement Instruments:

i. Pyranometer
ii. Thermocouple

38. Ismail H Ozsabuncuoglu [51]

Theoretical

Solar water heater

Attributes:

i. Material cost
ii. Other cost like transportation cost, steel stand, connecting parts, pipe insulation material & labor mounting the system
iii. Operation & maintenance cost (replacement of pipes & parts, antifreeze, repair insulation material, glass, paint & other)
iv. Interest
v. Inflation
vi. Production cost at manufacturer level
vii. Initial cost at user's level
viii. Operating cost
ix. Total cost
x. Cost comparison

39. A. Georgiev [52]

Experimental

Attributes:

i. Condenser temperature
ii. Condenser mass flow rate
iii. Medium fluid evaporator temperature
iv. COP
v. Efficiency

40. Yin Hang et al. [53]

Solar water heater

Theoretical

Attributes:

i. Location
ii. Comparison
iii. Economic prospective
iv. Energetic prospective
v. Environment prospective
vi. Auxiliary heater
vii. Month
viii. Solar fraction
ix. Energetic and environmental payback periods

41. Yasin Varol et al. [54]

Theoretical (ANN, ANFIS, SVM)

Experimental

Attributes:

i. PCM
ii. Heat output
iii. Efficiency
iv. Time

42. Ahmet Koca et al. [55]

Experimental

Solar water heater integrated

Attributes:

- Useful energy
- Exergy efficiency
- Day
- Solar irradiation
- Phase changing material (PCM)

43. Katharina Resch et al. [56]

    Review paper

    Attributes:

    i. Thermotropic layers

44. P.G. Loutzenhiser et al. [57]

    Experimental

    Attributes:

    i. Model validation for solar radiation calculation

45. K. Sopian et al. [58]

    Solar water heater

    Experimental

    Attributes:

    - Inlet temperature
    - Ambient temp.
    - Efficiency
    - Solar radiation
    - Outlet temperature

46. K. Chung et al. [59]

    Experimental

    Solar water heater

    Attributes:

    i. Wind speed
    ii. Wind uplift
    iii. Collector lifting
    iv. Guide plate

47. T.N. Anderson et al. [60]

    Experimental

    Theoretical

    Attributes:

i. Absorber color
ii. Efficiency
iii. Ambient temperature
iv. Inlet temperature

48. M.S. Sodha et al. [61]

Theoretical

Experimental

Attributes:

i. Insulation material
ii. Collector temperature
iii. Fluid flow stoppage

2.5.5.3 Coding scheme

Coding of attributes is done as per discussed in section 2.3.

2.5.5.4 Formation of IM for FPLSC:

A matrix m*n is developed as discussed in section 2.4 for FPLSC. Where m represents the number of attributes and n represents the number of papers. IM is developed as shown in fig.2.11 for FPLSC in which 48 papers are used and 183 attributes are collected. All the papers are not shown in the matrix because of page size limitations but these papers are easily seen on the excel sheet. As the attributes like type of work, output and instruments are only to give information about what type of work is done, what type of output is measured to see the effect and what type of instruments are used in these different experimental works. So these attributes are not quantifiable but only put Y in the cell of corresponding paper in which these are present to show their presence.

| Sr. No. | Attributes | Paper | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | P1 | P2 | P3 | P4 | P5 | P6 | P7 | P8 | P9 |
| | Input Attributes | | | | | | | | | |
| | 1. General | | | | | | | | | |
| | 1.1 Absorber Plate | N | N | Y | Y | N | N | N | Y | Y |
| 1 | Type Of Absorber | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | Absorber Shape | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | Micro Capillary Film (MCF) Voidage | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 | Absorber Area | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 2 | 0 |
| 5 | Absorber Material | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | Absorber Emissivity | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 7 | Thermal Conductivity Of Absorber | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8 | Selective Coating Of Absorber | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | Absorber Color | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 1.2 Tubes | Y | Y | Y | N | N | N | N | N | N |
| 10 | Heat Enhancement Devices | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11 | Length Of Tubes | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 12 | Number Of Tubes | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 13 | Diameter Of Riser | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 14 | Spacing B/W Risers | 2 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 1.3 Transparent Cover | Y | N | Y | N | N | N | N | N | N |
| 15 | Cover Material | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 16 | Absorptivity Of Cover | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 17 | Selective Coating Of Cover | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 18 | Transmittance Of Cover | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 19 | Number Of Covers | 3 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 |
| 20 | Optical Efficiency | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 21 | Reflectance Of Cover | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 22 | Cover Thickness | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 3. Operational | Y | Y | Y | Y | Y | N | Y | Y | Y |
| 23 | Tilt | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 4 |
| 24 | Flow Rate | 3 | 0 | 3 | 3 | 3 | 0 | 0 | 0 | 0 |
| 25 | Fluid Inlet Temp. | 4 | 4 | 4 | 0 | 0 | 0 | 4 | 0 | 0 |
| 26 | Fix To Wall | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 |
| | 4. Environment | N | N | Y | Y | Y | Y | Y | Y | Y |
| 27 | Solar Irradiation | 0 | 0 | 0 | 3 | 3 | 2 | 3 | 3 | 0 |
| 28 | Wind Velocity | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 3 |
| 29 | Ambient Temp. | 0 | 0 | 2 | 0 | 0 | 3 | 0 | 3 | 3 |
| | 2 Others | N | N | N | Y | N | N | Y | Y | N |
| 30 | Type Of Fluid | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 |
| 31 | Fluid Concentration | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 |
| 32 | Specific Heat Of Fluid | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 33 | Phase Changing Material | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 34 | Tracking | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 35 | Type Of Conditions B/W Absorber Plate & Glass Cover (Vacuum) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 |
| 36 | Different Arrangements Of Honey Comb Materials | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 37 | Distance B/W Absorber Plate & Honey Comb Material | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 38 | Distance B/W Transparent Cover & Honey Comb Material | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 39 | Insulation Material | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 40 | Thermal Capacitance Of All Components | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 41 | Collector Aging | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 42 | Hour Angle | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 43 | Declination Angle | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 44 | Latitude | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 45 | Roof Azimuthal Angle | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 46 | Roof Tilt Angle | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 47 | Location | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 48 | Efficiency | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 |
| 49 | Wind Heat Transfer Coefficient | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 50 | Absorber Plate Temperature | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 51 | Azimuthal Angle | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 52 | Incidence Angle | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 53 | Radiation Loss | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 54 | Date | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 55 | Time | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 56 | Deviation In Inlet Fluid Temperature | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 57 | Guide Plate | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 58 | Collector Lifting | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 59 | Fluid Flow Stoppage | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 5. Application | N | N | N | N | Y | Y | Y | Y | N |
| | 5.1 Effluent Evaporation System | N | N | N | N | Y | N | N | N | N |
| 60 | Concentration Of Effluent | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 |
| 61 | Relative Humidity | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 |
| | 5.2 Solar Still | N | N | N | N | N | Y | N | N | N |
| 62 | Water Depth | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 |
| 63 | Direction | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 |
| 64 | Type Of Water | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 65 | Operating Mode | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 5.3 Solar Water Heater | N | N | N | N | N | N | Y | N | N |
| 66 | Type Of Auxiliary Heater | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 5.3.1 Separate | N | N | N | N | N | N | N | N | N |
| | 5.3.1.1 Indirect Type | N | N | N | N | N | N | N | N | N |
| | Application | N | N | N | N | N | N | N | N | N |
| 67 | Material Cost | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 68 | Operation & Maintenance Cost | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 69 | Others Cost | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 70 | Interest Rate | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 71 | Inflation Rate | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 5.3.2 Integrated | N | N | N | N | N | N | N | N | N |
| | 5.3.2.1 Indirect Type | N | N | N | N | N | N | N | N | N |
| 72 | Recirculation Rate | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 73 | Heat Exchanger Tube Diameter | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 74 | Distance From Tank Walls | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 75 | Length Of Heat Exchanger | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 5.4 Solar Cooker | N | N | N | N | N | N | N | N | N |
| | 5.5 Solar Geyser Cum Distiller | N | N | N | N | N | N | N | N | N |
| | 5.6 Solar Oven | N | N | N | N | N | N | N | N | N |
| | 5.7 Heat Pump | N | N | N | N | N | N | N | N | N |
| 76 | Condenser Temp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 77 | Medium Fluid Evaporator Temp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 5.8 Solar Cooling System | N | N | N | N | N | N | N | N | N |
| | 5.9 Water Heater + Space Heating | N | N | N | N | N | N | N | Y | N |
| | 6. Theoretical | Y | Y | Y | Y | Y | N | N | N | Y |
| 78 | Energetic Prospective | N | N | N | N | N | N | N | N | N |
| 79 | Economic Prospective | N | N | N | N | N | N | N | N | N |
| 80 | Environment Prospective | N | N | N | N | N | N | N | N | N |
| 81 | Sensitivity Analysis (Regression Analysis) | N | N | N | N | N | N | N | N | N |
| 82 | FVM | N | N | Y | N | N | N | N | N | N |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 83 | Evaluate The Effect Of Glass Absorptivity On The System Performance | N | N | N | N | N | N | N | N | N |
| 84 | One Dimension Heat Eqn. | N | N | N | N | N | N | N | N | N |
| 85 | Two Dimension Heat Eqn. | N | N | N | N | N | N | N | N | N |
| 86 | Two Dimensional Finite Element Model | Y | N | N | N | N | N | N | N | N |
| 87 | Neural Network | N | N | N | N | N | N | N | N | N |
| 88 | Adaptive-Network- Based Fuzzy Inference System (ANFIS) | N | N | N | N | N | N | N | N | N |
| 89 | Support Vector Machines (SVM) | N | N | N | N | N | N | N | N | N |
| 90 | Mathematical Model | N | N | N | N | N | N | N | N | N |
| 91 | Exergy Analysis | N | N | N | N | N | N | N | N | N |
| 92 | Temp | N | N | N | Y | N | N | N | N | N |
| 93 | TOMP | N | N | N | N | N | N | N | N | N |
| 94 | FDM | N | N | N | N | N | N | N | N | N |
| | 7.Experimental | N | N | N | Y | Y | Y | Y | N | Y |
| 95 | Validation Of Models Of Radiation Calculation | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 8. Simulation | N | N | N | N | N | N | N | Y | N |
| 96 | CFD | N | N | N | N | N | N | N | N | N |
| 97 | TRNSYS | N | N | N | N | N | N | N | Y | N |
| 98 | TRNFLOW | N | N | N | N | N | N | N | Y | N |
| 99 | MATLAB | N | N | N | N | N | N | N | N | N |
| 100 | MINSUN | N | N | N | N | N | N | N | N | N |
| 101 | WATSUN | N | N | N | N | N | N | N | N | N |
| 102 | KOLEKTOR 2.2 | N | N | N | N | N | N | N | N | N |
| 103 | ANSYS | N | N | N | N | N | N | N | N | N |
| | 9. Review | | | | | | | | | |
| 104 | Thermotropic Layers | N | N | N | N | N | N | N | N | N |
| | 10. Instruments | N | N | N | N | Y | Y | Y | N | N |
| 105 | Thermocouple | N | N | N | N | Y | Y | Y | N | N |
| 106 | Millivoltmeter | N | N | N | N | Y | N | N | N | N |
| 107 | Pyranometer | N | N | N | N | N | N | N | N | N |
| 108 | Solar Cell | N | N | N | N | N | N | N | N | N |
| 109 | Piezometer Tube | N | N | N | N | Y | N | N | N | N |
| 110 | Mercury In Glass Thermometer | N | N | N | N | Y | N | Y | N | N |
| 111 | Wet & Dry Bulb Thermometer | N | N | N | N | Y | N | N | N | N |
| 112 | Digital Anemometer | N | N | N | N | Y | N | N | N | N |
| 113 | Kipp-ZononSolarimeter | N | N | N | N | Y | N | N | N | N |
| 114 | Surya Mapi | N | N | N | N | N | N | Y | N | N |
| 115 | Buoyancy Meter | N | N | N | N | N | N | N | N | N |
| 116 | Insolometer | N | N | N | N | N | N | N | N | N |
| 117 | PID Controller | N | N | N | N | N | N | N | N | N |
| 118 | Rotameter | N | N | N | N | N | N | N | N | N |
| 119 | PROVA (Av M-07) | N | N | N | N | N | N | N | N | N |
| 120 | Tes1333r Solar Meter | N | N | N | N | N | N | N | N | N |
| | Output Variables | | | | | | | | | |
| | 1 General | | | | | | | | | |
| 121 | Bottom Heat Loss | N | N | N | N | N | N | N | N | N |
| 122 | Absorber Plate Mean Temperature | N | N | Y | N | N | N | Y | N | N |
| 123 | Top Heat Loss | N | N | N | N | N | N | N | N | N |
| 124 | Top Loss Coefficient | N | N | N | N | N | N | N | N | Y |
| 125 | Efficiency | Y | Y | Y | N | N | N | Y | N | Y |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 126 | Nusslet No. | N | N | N | N | N | N | N | N | N |
| 127 | Rayleigh No. | N | N | N | N | N | N | N | N | N |
| 128 | Glass Temperature | N | N | N | N | N | Y | Y | N | N |
| 129 | Side Heat Loss | N | N | N | N | N | N | N | N | N |
| 130 | Edge Heat Loss | N | N | N | N | N | N | N | N | N |
| 131 | Fluid Temperature Variation Along The Tube | N | N | Y | N | N | N | N | N | N |
| 132 | Fluid Outlet And Inlet Temperature Difference | N | N | N | N | N | N | N | N | N |
| 133 | Pressure Drop | N | N | N | N | N | N | N | N | N |
| 134 | Absorber Mean And Ambient Temp. Difference | N | N | N | N | N | N | N | N | N |
| 135 | Thermal Performance | N | N | N | N | N | N | N | N | N |
| 136 | Useful Energy | N | N | N | N | N | N | N | N | N |
| 137 | Fluid Outlet Temperature | Y | N | Y | Y | N | N | N | N | N |
| 138 | Radiation Loss | N | N | N | N | N | N | N | N | N |
| 139 | Exergetic Efficiency | N | N | N | N | N | N | N | N | N |
| 140 | Tolerable Fluid Inlet Temperature Variation | N | N | N | N | N | N | N | N | N |
| 141 | Tolerable Variation In Temperature Difference Of Outlet And Inlet Temperature | N | N | N | N | N | N | N | N | N |
| 142 | Insulation Temperature | N | N | N | N | N | N | N | N | N |
| 143 | Compare The Results Of Two Dimension And One Dimension Model | N | N | Y | N | N | N | N | N | N |
| 144 | Tilt | N | N | N | N | N | N | N | N | N |
| 145 | Collector Area Ratio | N | N | N | N | N | N | N | N | N |
| 146 | Auxiliary Energy | N | N | N | N | N | N | N | N | N |
| 147 | 1st Glass Cover Inner Temp. | N | N | N | N | N | N | N | N | N |
| 148 | 1st Glass Cover Outer Temp. | N | N | N | N | N | N | N | N | N |
| 149 | 2nd Glass Cover Inner Temp. | N | N | N | N | N | N | N | N | N |
| 150 | Top Face Convective Heat Transfer Coefficient | N | N | N | N | N | N | N | N | N |
| 151 | Top Face Radiative Heat Transfer Coefficient | N | N | N | N | N | N | N | N | N |
| 152 | 2nd Glass Cover Outer Temp. | N | N | N | N | N | N | N | N | N |
| 153 | Cost | N | N | N | N | N | N | N | N | N |
| | 2 Application | | | | | | | | | |
| | 2.1 Solar Still | | | | | | | | | |
| 154 | Amount Of Water Produced In Still | N | N | N | N | N | Y | N | N | N |
| 155 | Condensed Temperature In Still | N | N | N | N | N | N | N | N | N |
| 156 | Glass Inside Temperature | N | N | N | N | N | N | N | N | N |
| 157 | Water Temperature In Still | N | N | N | N | N | Y | N | N | N |
| 158 | Vapor Temp. Produced In Still | N | N | N | N | N | N | N | N | N |
| 159 | Glass Outside Temperature | N | N | N | N | N | N | N | N | N |
| | 2.2 Solar Water Heater | | | | | | | | | |
| 160 | Solar Fraction | N | N | N | N | N | N | N | N | N |
| 161 | Energetic And Environmental Payback Periods | N | N | N | N | N | N | N | N | N |
| 162 | Wind Uplift | N | N | N | N | N | N | N | N | N |
| | 2.2.1 Separate | N | N | N | N | N | N | N | N | N |
| | 2.2.1.1 Indirect Type | N | N | N | N | N | N | N | N | N |
| 163 | Service Water Outlet Temperature | N | N | N | N | N | N | N | N | N |
| 164 | Production Cost At Manufacturer Level | N | N | N | N | N | N | N | N | N |
| 165 | Initial Cost At User Level | N | N | N | N | N | N | N | N | N |
| 166 | Total Cost | N | N | N | N | N | N | N | N | N |
| 167 | Cost Comparison | N | N | N | N | N | N | N | N | N |
| 168 | Cost Saving | N | N | N | N | N | N | N | N | N |
| | 2.2.2 Integrated Heat Exchanger | N | N | N | N | N | N | N | N | N |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2.2.2.1 Indirect Type | N | N | N | N | N | N | N | N | N |
| 169 | Useful Energy | N | N | N | N | N | N | N | N | N |
| 170 | Exergy Efficiency | N | N | N | N | N | N | N | N | N |
| 171 | Flow Path In The Tank | N | N | N | N | N | N | N | N | N |
| 172 | Velocity Distribution In The Tank | N | N | N | N | N | N | N | N | N |
| 173 | Temperature Of Tank | N | N | N | N | N | N | N | N | N |
| 174 | Service Water Outlet Temperature | N | N | N | N | N | N | N | N | N |
| 175 | Service Water Flow Rate | N | N | N | N | N | N | N | N | N |
| 176 | Storage Volume | N | N | N | N | N | N | N | N | N |
| 177 | Performance | N | N | N | N | N | N | N | N | N |
| 178 | Auxiliary Energy | N | N | N | N | N | N | N | N | N |
| | 2.3 Effluent Evaporation System | | | | | | | | | |
| 179 | Evaporation Rate | N | N | N | N | Y | N | N | N | N |
| | 2.4 Solar Cooker | | | | | | | | | |
| 180 | Absorber Temperature | N | N | N | N | N | N | N | N | N |
| | 2.5 Heat Pump | | | | | | | | | |
| 181 | Cop | N | N | N | N | N | N | N | N | N |
| 182 | Efficiency | N | N | N | N | N | N | N | N | N |
| | 2.6 Solar Geyser Cum Distiller | | | | | | | | | |
| 183 | Storage Temperature | N | N | N | N | N | N | N | N | N |
| 184 | Amount Of Water Produced | N | N | N | N | N | N | N | N | N |
| | 2.7 Water Heater + Space Heating | | | | | | | | | |
| 185 | Solar Fraction | N | N | N | N | N | N | N | Y | N |
| | 2.8 Solar Oven | N | N | N | N | N | N | N | N | N |
| 186 | Efficiency | N | N | N | N | N | N | N | N | N |
| | 2.8 Solar Cooling | N | N | N | N | N | N | N | N | N |
| 187 | Cop | N | N | N | N | N | N | N | N | N |
| 188 | Efficiency | N | N | N | N | N | N | N | N | N |
| | Sum | 14 | 9 | 19 | 11 | 17 | 13 | 11 | 13 | 12 |

| Sr. No. | Attributes | Paper | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | P 10 | P 11 | P 12 | P 13 | P 14 | P 15 | P 16 | P 17 | P 18 | P 19 | P 20 | P 21 |
| | Input Attributes | | | | | | | | | | | | |
| | 1. General | | | | | | | | | | | | |
| | 1.1 Absorber Plate | Y | Y | Y | Y | Y | Y | N | N | N | N | N | N |
| 1 | Type Of Absorber | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | Absorber Shape | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | Micro Capillary Film (MCF) Voidage | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 | Absorber Area | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | Absorber Material | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | Absorber Emissivity | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 | Thermal Conductivity Of Absorber | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8 | Selective Coating Of Absorber | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | Absorber Color | 0 | 0 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 1.2 Tubes | N | N | N | Y | Y | N | Y | Y | N | N | N | N |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10 | Heat Enhancement Devices | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 |
| 11 | Length Of Tubes | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 12 | Number Of Tubes | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 13 | Diameter Of Riser | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 |
| 14 | Spacing B/W Risers | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 1.3 Transparent Cover | Y | N | N | Y | Y | N | N | Y | N | N | N | N |
| 15 | Cover Material | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 16 | Absorptivity Of Cover | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 17 | Selective Coating Of Cover | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 18 | Transmittance Of Cover | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 19 | Number Of Covers | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 20 | Optical Efficiency | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 |
| 21 | Reflectance Of Cover | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 22 | Cover Thickness | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 3. Operational | N | Y | N | Y | N | Y | Y | Y | Y | N | N | N |
| 23 | Tilt | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 24 | Flow Rate | 0 | 0 | 0 | 3 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 |
| 25 | Fluid Inlet Temp. | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 4 | 3 | 0 | 0 | 0 |
| 26 | Fix To Wall | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 4. Environment | N | Y | Y | N | N | N | Y | Y | Y | Y | N | Y |
| 27 | Solar Irradiation | 0 | 3 | 3 | 0 | 0 | 0 | 3 | 3 | 3 | 3 | 0 | 3 |
| 28 | Wind Velocity | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 |
| 29 | Ambient Temp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 3 | 0 | 3 |
| | 2 Others | Y | N | Y | Y | Y | N | N | N | N | N | N | N |
| 30 | Type Of Fluid | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 31 | Fluid Concentration | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 32 | Specific Heat Of Fluid | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 33 | Phase Changing Material | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 34 | Tracking | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 35 | Type Of Conditions B/W Absorber Plate & Glass Cover (Vacuum) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 36 | Different Arrangements Of Honey Comb Materials | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 37 | Distance B/W Absorber Plate & Honey Comb Material | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 38 | Distance B/W Transparent Cover & Honey Comb Material | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 39 | Insulation Material | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 40 | Thermal Capacitance Of All Components | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 41 | Collector Aging | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 42 | Hour Angle | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 43 | Declination Angle | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 44 | Latitude | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 45 | Roof Azimuthal Angle | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 46 | Roof Tilt Angle | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 47 | Location | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 48 | Efficiency | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 49 | Wind Heat Transfer Coefficient | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 50 | Absorber Plate Temperature | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 51 | Azimuthal Angle | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 52 | Incidence Angle | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 53 | Radiation Loss | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 54 | Date | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 55 | Time | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 56 | Deviation In Inlet Fluid Temperature | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 57 | Guide Plate | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 58 | Collector Lifting | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 59 | Fluid Flow Stoppage | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 5. Application | N | N | Y | N | N | Y | N | N | N | Y | Y | Y |
| | 5.1 Effluent Evaporation System | N | N | N | N | N | N | N | N | N | N | N | N |
| 60 | Concentration Of Effluent | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 61 | Relative Humidity | 0 | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 5.2 Solar Still | N | N | N | N | N | N | N | N | N | Y | N | N |
| 62 | Water Depth | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 63 | Direction | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 | 0 |
| 64 | Type Of Water | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 |
| 65 | Operating Mode | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 |
| | 5.3 Solar Water Heater | N | N | Y | N | N | N | N | N | N | N | Y | N |
| 66 | Type Of Auxiliary Heater | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 5.3.1 Separate | N | N | Y | N | N | N | N | N | N | N | N | N |
| | 5.3.1.1 Indirect Type | N | N | Y | N | N | N | N | N | N | N | N | N |
| | Application | N | N | N | N | N | N | N | N | N | N | N | N |
| 67 | Material Cost | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 68 | Operation & Maintenance Cost | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 69 | Others Cost | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 70 | Interest Rate | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 71 | Inflation Rate | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 5.3.2 Integrated | N | N | N | N | N | N | N | N | N | N | Y | N |
| | 5.3.2.1 Indirect Type | N | N | N | N | N | N | N | N | N | N | Y | N |
| 72 | Recirculation Rate | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 |
| 73 | Heat Exchanger Tube Diameter | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 74 | Distance From Tank Walls | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 75 | Length Of Heat Exchanger | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 5.4 Solar Cooker | N | N | N | N | N | N | N | N | N | N | N | Y |
| | 5.5 Solar Geyser Cum Distiller | N | N | N | N | N | N | N | N | N | N | N | N |
| | 5.6 Solar Oven | N | N | N | N | N | N | N | N | N | N | N | N |
| | 5.7 Heat Pump | N | N | N | N | N | N | N | N | N | N | N | N |
| 76 | Condenser Temp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 77 | Medium Fluid Evaporator Temp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 5.8 Solar Cooling System | N | N | N | N | N | Y | N | N | N | N | N | N |
| | 5.9 Water Heater + Space Heating | N | N | N | N | N | N | N | N | N | N | N | N |
| | 6. Theoretical | Y | N | N | Y | Y | Y | N | Y | Y | N | Y | Y |
| 78 | Energetic Prospective | N | N | N | N | N | N | N | N | N | N | N | N |
| 79 | Economic Prospective | N | N | N | N | N | N | N | N | N | N | N | N |
| 80 | Environment Prospective | N | N | N | N | N | N | N | N | N | N | N | N |
| 81 | Sensitivity Analysis (Regression | N | N | N | N | N | N | N | N | Y | N | N | N |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Analysis) | | | | | | | | | | | | |
| 82 | FVM | N | N | N | N | N | N | N | N | N | N | N | N |
| 83 | Evaluate The Effect Of Glass Absorptivity On The System Performance | Y | N | N | N | N | N | N | N | N | N | N | N |
| 84 | One Dimension Heat Eqn. | N | N | N | N | N | N | N | N | N | N | N | N |
| 85 | Two Dimension Heat Eqn. | N | N | N | N | N | N | N | N | N | N | N | N |
| 86 | Two Dimensional Finite Element Model | N | N | N | N | N | N | N | N | N | N | N | N |
| 87 | Neural Network | N | N | N | N | N | N | N | N | N | N | N | N |
| 88 | Adaptive-Network- Based Fuzzy Inference System (ANFIS) | N | N | N | N | N | N | N | N | N | N | N | N |
| 89 | Support Vector Machines (SVM) | N | N | N | N | N | N | N | N | N | N | N | N |
| 90 | Mathematical Model | N | N | N | N | N | N | N | N | Y | N | N | N |
| 91 | Exergy Analysis | N | N | N | N | N | N | N | Y | N | N | N | N |
| 92 | Temp | N | N | N | N | N | N | N | N | N | N | N | N |
| 93 | TOMP | N | N | N | N | N | N | N | N | N | N | N | N |
| 94 | FDM | N | N | N | Y | N | N | N | N | N | N | N | N |
| | 7.Experimental | N | Y | N | Y | Y | N | Y | Y | Y | Y | Y | Y |
| 95 | Validation Of Models Of Radiation Calculation | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 8. Simulation | N | N | Y | N | N | N | N | N | N | N | Y | N |
| 96 | CFD | N | N | N | N | N | N | N | N | N | N | N | N |
| 97 | TRNSYS | N | N | Y | N | N | N | N | N | N | N | N | N |
| 98 | TRNFLOW | N | N | N | N | N | N | N | N | N | N | N | N |
| 99 | MATLAB | N | N | N | N | N | N | N | N | N | N | N | N |
| 100 | MINSUN | N | N | N | N | N | N | N | N | N | N | N | N |
| 101 | WATSUN | N | N | N | N | N | N | N | N | N | N | N | N |
| 102 | KOLEKTOR 2.2 | N | N | N | N | N | N | N | N | N | N | N | N |
| 103 | ANSYS | N | N | N | N | N | N | N | N | N | N | N | N |
| | 9. Review | | | | N | N | N | N | N | N | N | N | N |
| 104 | Thermotropic Layers | N | N | N | N | N | N | N | N | N | N | N | N |
| | 10. Instruments | N | Y | N | N | N | N | Y | N | N | N | N | N |
| 105 | Thermocouple | N | N | N | N | N | N | Y | N | N | Y | N | N |
| 106 | Millivoltmeter | N | N | N | N | N | N | N | N | N | N | N | N |
| 107 | Pyranometer | N | N | N | N | N | N | N | N | N | N | N | N |
| 108 | Solar Cell | N | N | N | N | N | N | N | N | N | N | N | N |
| 109 | Piezometer Tube | N | N | N | N | N | N | N | N | N | N | N | N |
| 110 | Mercury In Glass Thermometer | N | Y | N | N | N | N | N | N | N | N | N | N |
| 111 | Wet & Dry Bulb Thermometer | N | N | N | N | N | N | N | N | N | N | N | N |
| 112 | Digital Anemometer | N | N | N | N | N | N | N | N | N | Y | N | N |
| 113 | Kipp-ZononSolarimeter | N | N | N | N | N | N | N | N | N | Y | N | N |
| 114 | Surya Mapi | N | N | N | N | N | N | N | N | N | N | N | N |
| 115 | Buoyancy Meter | N | N | N | N | N | N | N | N | N | N | Y | N |
| 116 | Insolometer | N | N | N | N | N | N | N | N | N | N | N | N |
| 117 | PID Controller | N | N | N | N | N | N | Y | N | N | N | N | N |
| 118 | Rotameter | N | N | N | N | N | N | Y | N | N | N | N | N |
| 119 | PROVA (Av M-07) | N | N | N | N | N | N | N | N | N | N | N | N |
| 120 | Tes1333r Solar Meter | N | N | N | N | N | N | N | N | N | N | N | N |
| | Output Variables | | | | | | | | | | | | |
| | 1 General | | | | | | | | | | | | |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 121 | Bottom Heat Loss | N | N | N | N | N | N | N | N | N | N | N | N |
| 122 | Absorber Plate Mean Temperature | N | N | N | N | Y | N | N | N | N | N | N | N |
| 123 | Top Heat Loss | N | N | N | N | N | N | N | N | N | N | N | N |
| 124 | Top Loss Coefficient | N | N | N | N | N | N | N | N | N | N | N | N |
| 125 | Efficiency | N | Y | N | N | Y | Y | N | N | Y | N | N | N |
| 126 | Nusslet No. | N | N | N | N | N | N | N | N | N | N | N | N |
| 127 | Rayleigh No. | N | N | N | N | N | N | N | N | N | N | N | N |
| 128 | Glass Temperature | N | N | N | N | N | N | N | N | N | N | N | N |
| 129 | Side Heat Loss | N | N | N | N | N | N | N | N | N | N | N | N |
| 130 | Edge Heat Loss | N | N | N | N | N | N | N | N | N | N | N | N |
| 131 | Fluid Temperature Variation Along The Tube | N | N | N | N | N | N | N | N | N | N | N | N |
| 132 | Fluid Outlet And Inlet Temperature Difference | N | N | N | Y | N | N | Y | N | N | N | N | N |
| 133 | Pressure Drop | N | N | N | Y | N | N | N | N | N | N | N | N |
| 134 | Absorber Mean And Ambient Temp. Difference | N | N | N | N | Y | N | N | N | N | N | N | N |
| 135 | Thermal Performance | N | N | N | N | N | N | Y | N | N | N | N | N |
| 136 | Useful Energy | N | N | N | Y | Y | N | N | N | N | N | N | N |
| 137 | Fluid Outlet Temperature | N | Y | N | N | N | N | N | N | N | N | N | N |
| 138 | Radiation Loss | N | N | N | N | N | N | N | N | N | N | N | N |
| 139 | Exergetic Efficiency | N | N | N | N | N | N | N | Y | N | N | N | N |
| 140 | Tolerable Fluid Inlet Temperature Variation | N | N | N | N | N | N | N | N | Y | N | N | N |
| 141 | Tolerable Variation In Temperature Difference Of Outlet And Inlet Temperature | N | N | N | N | N | N | N | N | Y | N | N | N |
| 142 | Insulation Temperature | N | N | N | N | N | N | N | N | N | N | N | N |
| 143 | Compare The Results Of Two Dimension And One Dimension Model | N | N | N | N | N | N | N | N | N | N | N | N |
| 144 | Tilt | N | N | N | N | N | N | N | N | N | N | N | N |
| 145 | Collector Area Ratio | N | N | N | N | N | N | N | N | N | N | N | N |
| 146 | Auxiliary Energy | N | N | N | N | N | N | N | N | N | N | N | N |
| 147 | 1st Glass Cover Inner Temp. | Y | N | N | N | N | N | N | N | N | N | N | N |
| 148 | 1st Glass Cover Outer Temp. | Y | N | N | N | N | N | N | N | N | N | N | N |
| 149 | 2nd Glass Cover Inner Temp. | Y | N | N | N | N | N | N | N | N | N | N | N |
| 150 | Top Face Convective Heat Transfer Coefficient | Y | N | N | N | N | N | N | N | N | N | N | N |
| 151 | Top Face Radiative Heat Transfer Coefficient | Y | N | N | N | N | N | N | N | N | N | N | N |
| 152 | 2nd Glass Cover Outer Temp. | Y | N | N | N | N | N | N | N | N | N | N | N |
| 153 | Cost | N | N | N | N | Y | N | N | N | N | N | N | N |
| | 2 Application | | | | | | | | | | | | |
| | 2.1 Solar Still | | | | | | | | | | | | |
| 154 | Amount Of Water Produced In Still | N | N | N | N | N | N | N | N | N | Y | N | N |
| 155 | Condensed Temperature In Still | N | N | N | N | N | N | N | N | N | Y | N | N |
| 156 | Glass Inside Temperature | N | N | N | N | N | N | N | N | N | N | N | N |
| 157 | Water Temperature In Still | N | N | N | N | N | N | N | N | N | N | N | N |
| 158 | Vapor Temp. Produced In Still | N | N | N | N | N | N | N | N | N | N | N | N |
| 159 | Glass Outside Temperature | N | N | N | N | N | N | N | N | N | N | N | N |
| | 2.2 Solar Water Heater | | | | | | | | | | | | |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 160 | Solar Fraction | N | N | N | N | N | N | N | N | N | N | N | N |
| 161 | Energetic And Environmental Payback Periods | N | N | N | N | N | N | N | N | N | N | N | N |
| 162 | Wind Uplift | N | N | N | N | N | N | N | N | N | N | N | N |
| | 2.2.1 Separate | | | | | | | | | | | | |
| | 2.2.1.1 Indirect Type | | | | | | | | | | | | |
| 163 | Service Water Outlet Temperature | N | N | N | N | N | N | N | N | N | N | N | N |
| 164 | Production Cost At Manufacturer Level | N | N | N | N | N | N | N | N | N | N | N | N |
| 165 | Initial Cost At User Level | N | N | N | N | N | N | N | N | N | N | N | N |
| 166 | Total Cost | N | N | N | N | N | N | N | N | N | N | N | N |
| 167 | Cost Comparison | N | N | N | N | N | N | N | N | N | N | N | N |
| 168 | Cost Saving | N | N | N | N | N | N | N | N | N | N | N | N |
| | 2.2.2 Integrated Heat Exchanger | | | | | | | | | | | | |
| | 2.2.2.1 Indirect Type | | | | | | | | | | | | |
| 169 | Useful Energy | N | N | Y | N | N | N | N | N | N | N | N | N |
| 170 | Exergy Efficiency | N | N | N | N | N | N | N | N | N | N | N | N |
| 171 | Flow Path In The Tank | N | N | N | N | N | N | N | N | N | N | Y | N |
| 172 | Velocity Distribution In The Tank | N | N | N | N | N | N | N | N | N | N | Y | N |
| 173 | Temperature Of Tank | N | N | N | N | N | N | N | N | N | N | Y | N |
| 174 | Service Water Outlet Temperature | N | N | N | N | N | N | N | N | N | N | Y | N |
| 175 | Service Water Flow Rate | N | N | N | N | N | N | N | N | N | N | N | N |
| 176 | Storage Volume | N | N | N | N | N | N | N | N | N | N | N | N |
| 177 | Performance | N | N | N | N | N | N | N | N | N | N | N | N |
| 178 | Auxiliary Energy | N | N | Y | N | N | N | N | N | N | N | N | N |
| | 2.3 Effluent Evaporation System | | | | | | | | | | | | |
| 179 | Evaporation Rate | N | N | N | N | N | N | N | N | N | N | N | N |
| | 2.4 Solar Cooker | | | | | | | | | | | | |
| 180 | Absorber Temperature | N | N | N | N | N | N | N | N | N | N | N | Y |
| | 2.5 Heat Pump | | | | | | | | | | | | |
| 181 | Cop | N | N | N | N | N | N | N | N | N | N | N | N |
| 182 | Efficiency | N | N | N | N | N | N | N | N | N | N | N | N |
| | 2.6 Solar Geyser Cum Distiller | | | | | | | | | | | | |
| 183 | Storage Temperature | N | N | N | N | N | N | N | N | N | N | N | N |
| 184 | Amount Of Water Produced | N | N | N | N | N | N | N | N | N | N | N | N |
| | 2.7 Water Heater + Space Heating | | | | | | | | | | | | |
| 185 | Solar Fraction | N | N | N | N | N | N | N | N | N | N | N | N |
| | 2.8 Solar Oven | | | | | | | | | | | | |
| 186 | Efficiency | N | N | N | N | N | N | N | N | N | N | N | N |
| | 2.8 Solar Cooling | | | | | | | | | | | | |
| 187 | Cop | N | N | N | N | N | Y | N | N | N | N | N | N |
| 188 | Efficiency | N | N | N | N | N | Y | N | N | N | N | N | N |
| | Sum | 14 | 10 | 7 | 16 | 6 | 3 | 9 | 17 | 9 | 11 | 3 | 6 |

| Sr. | Attributes | Paper |
|---|---|---|

| No. | | P 22 | P 23 | P 24 | P 25 | P 26 | P 27 | P 28 | P 29 | P 30 | P 31 | P 32 | P 33 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Input Attributes | | | | | | | | | | | | |
| | 1. General | | | | | | | | | | | | |
| | 1.1 Absorber Plate | N | N | N | N | N | N | N | N | N | N | N | N |
| 1 | Type Of Absorber | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | Absorber Shape | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | Micro Capillary Film (MCF) Voidage | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 | Absorber Area | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | Absorber Material | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | Absorber Emissivity | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 | Thermal Conductivity Of Absorber | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8 | Selective Coating Of Absorber | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | Absorber Color | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 1.2 Tubes | N | N | N | N | N | N | N | N | N | N | N | N |
| 10 | Heat Enhancement Devices | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11 | Length Of Tubes | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 12 | Number Of Tubes | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 13 | Diameter Of Riser | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 14 | Spacing B/W Risers | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 1.3 Transparent Cover | N | N | N | N | N | N | Y | N | N | N | N | N |
| 15 | Cover Material | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 16 | Absorptivity Of Cover | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 17 | Selective Coating Of Cover | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 |
| 18 | Transmittance Of Cover | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 |
| 19 | Number Of Covers | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 20 | Optical Efficiency | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 21 | Reflectance Of Cover | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 |
| 22 | Cover Thickness | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 3. Operational | Y | Y | Y | N | N | Y | N | N | Y | Y | N | N |
| 23 | Tilt | 0 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 |
| 24 | Flow Rate | 0 | 0 | 2 | 0 | 0 | 3 | 0 | 0 | 4 | 0 | 0 | 0 |
| 25 | Fluid Inlet Temp. | 3 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 3 | 0 | 0 | 0 |
| 26 | Fix To Wall | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 4. Environment | Y | Y | Y | Y | Y | Y | Y | Y | Y | N | N | N |
| 27 | Solar Irradiation | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 0 | 3 | 0 | 0 | 0 |
| 28 | Wind Velocity | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 3 | 0 | 0 | 0 | 0 |
| 29 | Ambient Temp. | 3 | 0 | 0 | 3 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 2 Others | N | Y | N | Y | N | Y | N | Y | N | Y | Y | Y |
| 30 | Type Of Fluid | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| 31 | Fluid Concentration | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| 32 | Specific Heat Of Fluid | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 33 | Phase Changing Material | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0 |
| 34 | Tracking | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 35 | Type Of Conditions B/W Absorber Plate & Glass Cover (Vacuum) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 36 | Different Arrangements Of Honey Comb Materials | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 37 | Distance B/W Absorber Plate & Honey Comb Material | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 38 | Distance B/W Transparent Cover & Honey Comb Material | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 39 | Insulation Material | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 40 | Thermal Capacitance Of All Components | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 |
| 41 | Collector Aging | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 |
| 42 | Hour Angle | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 |
| 43 | Declination Angle | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 |
| 44 | Latitude | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 1 |
| 45 | Roof Azimuthal Angle | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 |
| 46 | Roof Tilt Angle | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 |
| 47 | Location | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 48 | Efficiency | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 49 | Wind Heat Transfer Coefficient | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 50 | Absorber Plate Temperature | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 51 | Azimuthal Angle | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 52 | Incidence Angle | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 |
| 53 | Radiation Loss | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 |
| 54 | Date | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 55 | Time | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 56 | Deviation In Inlet Fluid Temperature | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 57 | Guide Plate | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 58 | Collector Lifting | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 59 | Fluid Flow Stoppage | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 5. Application | Y | N | Y | N | N | N | N | N | N | N | N | N |
| | 5.1 Effluent Evaporation System | N | N | N | N | N | N | N | N | N | N | N | N |
| 60 | Concentration Of Effluent | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 61 | Relative Humidity | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 5.2 Solar Still | N | N | N | N | N | N | N | N | N | N | N | N |
| 62 | Water Depth | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 63 | Direction | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 64 | Type Of Water | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 65 | Operating Mode | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 5.3 Solar Water Heater | N | N | N | N | N | N | N | N | N | N | N | N |
| 66 | Type Of Auxiliary Heater | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 5.3.1 Separate | N | N | N | N | N | N | N | N | N | N | N | N |
| | 5.3.1.1 Indirect Type | N | N | N | N | N | N | N | N | N | N | N | N |
| | Application | N | N | N | N | N | N | N | N | N | N | N | N |
| 67 | Material Cost | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 68 | Operation & Maintenance Cost | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 69 | Others Cost | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 70 | Interest Rate | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 71 | Inflation Rate | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 5.3.2 Integrated | N | N | N | N | N | N | N | N | N | N | N | N |
| | 5.3.2.1 Indirect Type | N | N | N | N | N | N | N | N | N | N | N | N |
| 72 | Recirculation Rate | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 73 | Heat Exchanger Tube Diameter | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 74 | Distance From Tank Walls | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 75 | Length Of Heat Exchanger | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 5.4 Solar Cooker | N | N | N | N | N | N | N | N | N | N | N | N |
| | 5.5 Solar Geyser Cum Distiller | Y | N | N | N | N | N | N | N | N | N | N | N |
| | 5.6 Solar Oven | N | N | Y | N | N | N | N | N | N | N | N | N |
| | 5.7 Heat Pump | N | N | N | N | N | N | N | N | N | N | N | N |
| 76 | Condenser Temp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 77 | Medium Fluid Evaporator Temp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 5.8 Solar Cooling System | N | N | N | N | N | N | N | N | N | N | N | N |
| | 5.9 Water Heater + Space Heating | N | N | N | N | N | N | N | N | N | N | N | N |
| | 6. Theoretical | N | Y | N | N | N | N | N | Y | Y | Y | Y | Y |
| 78 | Energetic Prospective | N | N | N | N | N | N | N | N | N | N | N | N |
| 79 | Economic Prospective | N | N | N | N | N | N | N | N | N | N | N | N |
| 80 | Environment Prospective | N | N | N | N | N | N | N | N | N | N | N | N |
| 81 | Sensitivity Analysis (Regression Analysis) | N | N | N | N | N | N | N | N | N | N | N | N |
| 82 | FVM | N | N | N | N | N | N | N | N | N | N | N | N |
| 83 | Evaluate The Effect Of Glass Absorptivity On The System Performance | N | N | N | N | N | N | N | N | N | N | N | N |
| 84 | One Dimension Heat Eqn. | N | N | N | N | N | N | N | N | N | N | N | N |
| 85 | Two Dimension Heat Eqn. | N | N | N | N | N | N | N | N | N | N | N | N |
| 86 | Two Dimensional Finite Element Model | N | N | N | N | N | N | N | N | N | N | N | N |
| 87 | Neural Network | N | Y | N | N | N | N | N | N | N | N | N | N |
| 88 | Adaptive-Network- Based Fuzzy Inference System (ANFIS) | N | N | N | N | N | N | N | N | N | N | N | N |
| 89 | Support Vector Machines (SVM) | N | N | N | N | N | N | N | N | N | N | N | N |
| 90 | Mathematical Model | N | N | N | N | N | N | N | Y | N | Y | N | Y |
| 91 | Exergy Analysis | N | N | N | N | N | N | N | N | N | N | N | N |
| 92 | Temp | N | N | N | N | N | N | N | N | N | N | N | N |
| 93 | TOMP | N | N | N | N | N | N | N | N | Y | N | N | N |
| 94 | FDM | N | N | N | N | N | N | N | N | N | N | N | N |
| | 7.Experimental | Y | N | Y | Y | Y | Y | Y | Y | N | N | N | N |
| 95 | Validation Of Models Of Radiation Calculation | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | N | N |
| | 8. Simulation | N | N | N | N | N | N | N | N | N | Y | N | N |
| 96 | CFD | N | N | N | N | N | N | N | N | N | N | N | N |
| 97 | TRNSYS | N | N | N | N | N | N | N | N | N | N | N | N |
| 98 | TRNFLOW | N | N | N | N | N | N | N | N | N | N | N | N |
| 99 | MATLAB | N | N | N | N | N | N | N | Y | N | Y | N | N |
| 100 | MINSUN | N | N | N | N | N | N | N | N | N | N | N | N |
| 101 | WATSUN | N | N | N | N | N | N | N | N | N | N | N | N |
| 102 | KOLEKTOR 2.2 | N | N | N | N | N | N | N | N | N | N | N | N |
| 103 | ANSYS | N | N | N | N | N | N | N | N | N | N | N | N |
| | 9. Review | N | N | N | N | N | N | N | N | N | N | N | N |
| 104 | Thermotropic Layers | N | N | N | N | N | N | N | N | N | N | N | N |
| | 10. Instruments | N | N | N | N | N | N | N | N | N | N | N | N |
| 105 | Thermocouple | Y | N | N | N | Y | Y | N | N | N | N | N | N |
| 106 | Millivoltmeter | N | N | N | N | N | N | N | N | N | N | N | N |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 107 | Pyranometer | N | N | N | N | N | N | N | N | N | N | N | N |
| 108 | Solar Cell | N | N | N | N | N | N | N | N | N | N | N | N |
| 109 | Piezometer Tube | N | N | N | N | N | N | N | N | N | N | N | N |
| 110 | Mercury In Glass Thermometer | N | N | Y | N | N | N | N | N | N | N | N | N |
| 111 | Wet & Dry Bulb Thermometer | N | N | N | N | N | N | N | N | N | N | N | N |
| 112 | Digital Anemometer | N | N | N | N | N | N | N | N | N | N | N | N |
| 113 | Kipp-ZononSolarimeter | N | N | N | N | N | N | N | N | N | N | N | N |
| 114 | Surya Mapi | N | N | N | N | N | N | N | N | N | N | N | N |
| 115 | Buoyancy Meter | N | N | N | N | N | N | N | N | N | N | N | N |
| 116 | Insolometer | Y | N | N | N | N | N | N | N | N | N | N | N |
| 117 | PID Controller | N | N | N | N | N | N | N | N | N | N | N | N |
| 118 | Rotameter | N | N | N | N | N | Y | N | N | N | N | N | N |
| 119 | PROVA (Av M-07) | N | N | N | N | N | Y | N | N | N | N | N | N |
| 120 | Tes1333r Solar Meter | N | N | N | N | N | Y | N | N | N | N | N | N |
| | Output Variables | | | | | | | | | | | | |
| | 1 General | | | | | | | | | | | | |
| 121 | Bottom Heat Loss | N | N | N | N | Y | N | N | N | N | N | N | N |
| 122 | Absorber Plate Mean Temperature | N | N | Y | N | N | N | N | N | N | N | N | N |
| 123 | Top Heat Loss | N | N | N | N | Y | N | N | N | N | N | N | N |
| 124 | Top Loss Coefficient | N | N | N | N | N | N | N | N | N | N | N | N |
| 125 | Efficiency | Y | Y | N | Y | N | Y | Y | N | N | N | N | N |
| 126 | Nusslet No. | N | N | N | N | N | N | N | N | N | N | N | N |
| 127 | Rayleigh No. | N | N | N | N | N | N | N | N | N | N | N | N |
| 128 | Glass Temperature | N | N | N | N | N | N | N | N | N | N | N | N |
| 129 | Side Heat Loss | N | N | N | N | Y | N | N | N | N | N | N | N |
| 130 | Edge Heat Loss | N | N | N | N | Y | N | N | N | N | N | N | N |
| 131 | Fluid Temperature Variation Along The Tube | N | N | N | N | N | N | N | N | N | N | N | N |
| 132 | Fluid Outlet And Inlet Temperature Difference | N | N | N | N | N | N | N | N | N | N | N | N |
| 133 | Pressure Drop | N | N | N | N | N | N | N | N | N | N | N | N |
| 134 | Absorber Mean And Ambient Temp. Difference | N | N | N | N | N | N | N | N | N | N | N | N |
| 135 | Thermal Performance | N | N | N | N | N | N | N | N | N | N | N | N |
| 136 | Useful Energy | N | N | N | N | N | N | N | Y | N | N | N | N |
| 137 | Fluid Outlet Temperature | Y | N | N | Y | N | Y | N | Y | N | N | N | N |
| 138 | Radiation Loss | N | N | N | N | N | N | N | N | N | N | N | N |
| 139 | Exergetic Efficiency | N | N | N | N | N | N | N | N | Y | N | N | N |
| 140 | Tolerable Fluid Inlet Temperature Variation | N | N | N | N | N | N | N | N | N | N | N | N |
| 141 | Tolerable Variation In Temperature Difference Of Outlet And Inlet Temperature | N | N | N | N | N | N | N | N | N | N | N | N |
| 142 | Insulation Temperature | N | N | N | N | N | N | N | N | N | N | N | N |
| 143 | Compare The Results Of Two Dimension And One Dimension Model | N | N | N | N | N | N | N | N | N | N | N | N |
| 144 | Tilt | N | N | N | N | N | N | N | N | N | Y | N | Y |
| 145 | Collector Area Ratio | N | N | N | N | N | N | N | N | N | N | Y | N |
| 146 | Auxiliary Energy | N | N | N | N | N | N | N | N | N | N | N | N |
| 147 | $1^{st}$ Glass Cover Inner Temp. | N | N | N | N | N | N | N | N | N | N | N | N |
| 148 | $1^{st}$ Glass Cover Outer Temp. | N | N | N | N | N | N | N | N | N | N | N | N |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 149 | $2^{nd}$ Glass Cover Inner Temp. | N | N | N | N | N | N | N | N | N | N | N | N |
| 150 | Top Face Convective Heat Transfer Coefficient | N | N | N | N | N | N | N | N | N | N | N | N |
| 151 | Top Face Radiative Heat Transfer Coefficient | N | N | N | N | N | N | N | N | N | N | N | N |
| 152 | $2^{nd}$ Glass Cover Outer Temp. | N | N | N | N | N | N | N | N | N | N | N | N |
| 153 | Cost | N | N | N | N | N | N | N | N | N | N | N | N |
| | 2 Application | | | | | | | | | | | | |
| | 2.1 Solar Still | | | | | | | | | | | | |
| 154 | Amount Of Water Produced In Still | N | N | N | N | N | N | N | N | N | N | N | N |
| 155 | Condensed Temperature In Still | N | N | N | N | N | N | N | N | N | N | N | N |
| 156 | Glass Inside Temperature | N | N | N | N | N | N | N | N | N | N | N | N |
| 157 | Water Temperature In Still | N | N | N | N | N | N | N | N | N | N | N | N |
| 158 | Vapor Temp. Produced In Still | N | N | N | N | N | N | N | N | N | N | N | N |
| 159 | Glass Outside Temperature | N | N | N | N | N | N | N | N | N | N | N | N |
| | 2.2 Solar Water Heater | | | | | | | | | | | | |
| 160 | Solar Fraction | N | N | N | N | N | N | N | N | N | N | N | N |
| 161 | Energetic And Environmental Payback Periods | N | N | N | N | N | N | N | N | N | N | N | N |
| 162 | Wind Uplift | N | N | N | N | N | N | N | N | N | N | | |
| | 2.2.1 Separate | | | | | | | | | | | | |
| | 2.2.1.1 Indirect Type | | | | | | | | | | | | |
| 163 | Service Water Outlet Temperature | N | N | N | N | N | N | N | N | N | N | N | N |
| 164 | Production Cost At Manufacturer Level | N | N | N | N | N | N | N | N | N | N | N | N |
| 165 | Initial Cost At User Level | N | N | N | N | N | N | N | N | N | N | N | N |
| 166 | Total Cost | N | N | N | N | N | N | N | N | N | N | N | N |
| 167 | Cost Comparison | N | N | N | N | N | N | N | N | N | N | N | N |
| 168 | Cost Saving | N | N | N | N | N | N | N | N | N | N | N | N |
| | 2.2.2 Integrated Heat Exchanger | | | | | | | | | | | | |
| | 2.2.2.1 Indirect Type | | | | | | | | | | | | |
| 169 | Useful Energy | N | N | N | N | N | N | N | N | N | N | N | N |
| 170 | Exergy Efficiency | N | N | N | N | N | N | N | N | N | N | N | N |
| 171 | Flow Path In The Tank | N | N | N | N | N | N | N | N | N | N | N | N |
| 172 | Velocity Distribution In The Tank | N | N | N | N | N | N | N | N | N | N | N | N |
| 173 | Temperature Of Tank | N | N | N | N | N | N | N | N | N | N | N | N |
| 174 | Service Water Outlet Temperature | N | N | N | N | N | N | N | N | N | N | N | N |
| 175 | Service Water Flow Rate | N | N | N | N | N | N | N | N | N | N | N | N |
| 176 | Storage Volume | N | N | N | N | N | N | N | N | N | N | N | N |
| 177 | Performance | N | N | N | N | N | N | N | N | N | N | N | N |
| 178 | Auxiliary Energy | N | N | N | N | N | N | N | N | N | N | N | N |
| | 2.3 Effluent Evaporation System | | | | | | | | | | | | |
| 179 | Evaporation Rate | N | N | N | N | N | N | N | N | N | N | N | N |
| | 2.4 Solar Cooker | | | | | | | | | | | | |
| 180 | Absorber Temperature | N | N | N | N | N | N | N | N | N | N | N | N |
| | 2.5 Heat Pump | | | | | | | | | | | | |
| 181 | Cop | N | N | N | N | N | N | N | N | N | N | N | N |
| 182 | Efficiency | N | N | N | N | N | N | N | N | N | N | N | N |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2.6 Solar Geyser Cum Distiller | | | | | | | | | | | | |
| 183 | Storage Temperature | Y | N | N | N | N | N | N | N | N | N | N | N |
| 184 | Amount Of Water Produced | Y | N | N | N | N | N | N | N | N | N | N | N |
| | 2.7 Water Heater + Space Heating | | | | | | | | | | | | |
| 185 | Solar Fraction | N | N | N | N | N | N | N | N | N | N | N | N |
| | 2.8 Solar Oven | | | | | | | | | | | | |
| 186 | Efficiency | N | N | Y | N | N | N | N | N | N | N | N | N |
| | 2.8 Solar Cooling | | | | | | | | | | | | |
| 187 | Cop | N | N | N | N | N | N | N | N | N | N | N | N |
| 188 | Efficiency | N | N | N | N | N | N | N | N | N | N | N | N |
| | Sum | 9 | 17 | 7 | 10 | 6 | 16 | 12 | 16 | 10 | 16 | 8 | 1 |

| Sr. No. | Attributes | Paper | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | P 34 | P 35 | P 36 | P 37 | P 38 | P 39 | P 40 | P 41 | P 42 | P 43 | P 44 | P 45 |
| | Input Attributes | | | | | | | | | | | | |
| | 1. General | | | | | | | | | | | | |
| | 1.1 Absorber Plate | N | N | N | N | N | N | N | N | N | N | N | N |
| 1 | Type Of Absorber | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | Absorber Shape | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | Micro Capillary Film (MCF) Voidage | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 | Absorber Area | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | Absorber Material | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | Absorber Emissivity | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 | Thermal Conductivity Of Absorber | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8 | Selective Coating Of Absorber | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | Absorber Color | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 1.2 Tubes | N | N | N | N | N | N | N | N | N | N | N | N |
| 10 | Heat Enhancement Devices | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11 | Length Of Tubes | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 12 | Number Of Tubes | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 13 | Diameter Of Riser | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 14 | Spacing B/W Risers | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 1.3 Transparent Cover | N | N | N | N | N | N | N | N | N | N | N | N |
| 15 | Cover Material | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 16 | Absorptivity Of Cover | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 17 | Selective Coating Of Cover | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 18 | Transmittance Of Cover | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 19 | Number Of Covers | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 20 | Optical Efficiency | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 21 | Reflectance Of Cover | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 22 | Cover Thickness | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 3. Operational | N | N | Y | N | N | Y | N | N | N | Y | N | Y |
| 23 | Tilt | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 24 | Flow Rate | 0 | 0 | 3 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 25 | Fluid Inlet Temp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| 26 | Fix To Wall | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 4. Environment | N | N | Y | Y | N | N | N | N | Y | Y | Y | Y |
| 27 | Solar Irradiation | 0 | 0 | 3 | 3 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 3 |
| 28 | Wind Velocity | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 29 | Ambient Temp. | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| | 2 Others | Y | Y | N | N | N | N | Y | Y | Y | N | N | N |
| 30 | Type Of Fluid | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 31 | Fluid Concentration | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 32 | Specific Heat Of Fluid | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 33 | Phase Changing Material | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 0 | 0 | 0 |
| 34 | Tracking | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 35 | Type Of Conditions B/W Absorber Plate & Glass Cover (Vacuum) | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 36 | Different Arrangements Of Honey Comb Materials | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 37 | Distance B/W Absorber Plate & Honey Comb Material | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 38 | Distance B/W Transparent Cover & Honey Comb Material | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 39 | Insulation Material | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 40 | Thermal Capacitance Of All Components | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 41 | Collector Aging | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 42 | Hour Angle | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 43 | Declination Angle | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 44 | Latitude | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 45 | Roof Azimuthal Angle | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 46 | Roof Tilt Angle | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 47 | Location | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 |
| 48 | Efficiency | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 49 | Wind Heat Transfer Coefficient | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 50 | Absorber Plate Temperature | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 51 | Azimuthal Angle | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 52 | Incidence Angle | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 53 | Radiation Loss | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 54 | Date | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 55 | Time | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 |
| 56 | Deviation In Inlet Fluid Temperature | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 57 | Guide Plate | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 58 | Collector Lifting | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 59 | Fluid Flow Stoppage | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 5. Application | N | Y | Y | Y | Y | Y | Y | Y | Y | N | N | Y |
| | 5.1 Effluent Evaporation System | N | N | N | N | N | N | N | N | N | N | N | N |
| 60 | Concentration Of Effluent | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 61 | Relative Humidity | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 5.2 Solar Still | N | N | N | Y | N | N | N | N | N | N | N | N |
| 62 | Water Depth | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 63 | Direction | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 64 | Type Of Water | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 65 | Operating Mode | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 5.3 Solar Water Heater | N | Y | Y | N | Y | N | Y | Y | Y | N | N | Y |
| 66 | Type Of Auxiliary Heater | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 |
| | 5.3.1 Separate | N | N | Y | N | Y | N | N | N | N | N | N | N |
| | 5.3.1.1 Indirect Type | N | N | N | N | Y | N | N | N | N | N | N | N |
| | Application | N | N | N | N | N | N | N | N | N | N | N | N |
| 67 | Material Cost | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 68 | Operation & Maintenance Cost | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 69 | Others Cost | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 70 | Interest Rate | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 71 | Inflation Rate | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 5.3.2 Integrated | N | Y | N | N | N | N | N | N | Y | N | N | N |
| | 5.3.2.1 Indirect Type | N | Y | N | N | N | N | N | N | Y | N | N | N |
| 72 | Recirculation Rate | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 73 | Heat Exchanger Tube Diameter | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 74 | Distance From Tank Walls | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 75 | Length Of Heat Exchanger | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 5.4 Solar Cooker | N | N | N | N | N | N | N | N | N | N | N | N |
| | 5.5 Solar Geyser Cum Distiller | N | N | N | N | N | N | N | N | N | N | N | N |
| | 5.6 Solar Oven | N | N | N | N | N | N | N | N | N | N | N | N |
| | 5.7 Heat Pump | N | N | N | N | N | Y | N | N | N | N | N | N |
| 76 | Condenser Temp. | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| 77 | Medium Fluid Evaporator Temp. | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 5.8 Solar Cooling System | N | N | N | N | N | N | N | N | N | N | N | N |
| | 5.9 Water Heater + Space Heating | N | N | N | N | N | N | N | N | N | N | N | N |
| | 6. Theoretical | Y | N | N | N | Y | Y | Y | Y | N | N | N | N |
| 78 | Energetic Prospective | N | N | N | N | N | N | Y | N | N | N | N | N |
| 79 | Economic Prospective | N | N | N | N | N | N | Y | N | N | N | N | N |
| 80 | Environment Prospective | N | N | N | N | N | N | Y | N | N | N | N | N |
| 81 | Sensitivity Analysis (Regression Analysis) | Y | N | N | N | N | N | N | N | N | N | N | N |
| 82 | FVM | N | N | N | N | N | N | N | N | N | N | N | N |
| 83 | Evaluate The Effect Of Glass Absorptivity On The System Performance | N | N | N | N | N | N | N | N | N | N | N | N |
| 84 | One Dimension Heat Eqn. | N | N | N | N | N | N | N | N | N | N | N | N |
| 85 | Two Dimension Heat Eqn. | N | N | N | N | N | N | N | N | N | N | N | N |
| 86 | Two Dimensional Finite Element Model | N | N | N | N | N | N | N | N | N | N | N | N |
| 87 | Neural Network | N | N | N | N | N | N | N | Y | N | N | N | N |
| 88 | Adaptive-Network- Based Fuzzy Inference System (ANFIS) | N | N | N | N | N | N | N | Y | N | N | N | N |
| 89 | Support Vector Machines (SVM) | N | N | N | N | N | N | N | Y | N | N | N | N |
| 90 | Mathematical Model | N | N | N | N | N | N | N | N | N | N | N | N |
| 91 | Exergy Analysis | N | N | N | N | N | N | N | N | N | N | N | N |
| 92 | Temp | N | N | N | N | N | N | N | N | N | N | N | N |
| 93 | TOMP | N | N | N | N | N | N | N | N | N | N | N | N |
| 94 | FDM | N | N | N | N | N | N | N | N | N | N | N | N |
| | 7.Experimental | N | Y | Y | Y | N | Y | N | Y | Y | N | Y | Y |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 95 | Validation Of Models Of Radiation Calculation | N | N | N | N | N | N | N | N | N | N | 4 | N |
| | 8. Simulation | N | Y | Y | Y | N | N | N | N | N | N | N | N |
| 96 | CFD | N | Y | N | N | N | N | N | N | N | N | N | N |
| 97 | TRNSYS | N | N | Y | N | N | N | N | N | N | N | N | N |
| 98 | TRNFLOW | N | N | N | N | N | N | N | N | N | N | N | N |
| 99 | MATLAB | N | N | N | N | N | N | N | N | N | N | N | N |
| 100 | MINSUN | N | N | N | N | N | N | N | N | N | N | N | N |
| 101 | WATSUN | N | N | N | N | N | N | N | N | N | N | N | N |
| 102 | KOLEKTOR 2.2 | N | N | N | N | N | N | N | N | N | N | N | N |
| 103 | ANSYS | N | N | N | Y | N | N | N | N | N | N | N | N |
| | 9. Review | N | N | N | N | N | N | N | N | N | Y | N | N |
| 104 | Thermotropic Layers | N | N | N | N | N | N | N | N | N | Y | N | N |
| | 10. Instruments | Y | Y | N | Y | N | N | N | N | N | N | N | N |
| 105 | Thermocouple | N | Y | N | Y | N | N | N | N | N | N | N | N |
| 106 | Millivoltmeter | N | N | N | N | N | N | N | N | N | N | N | N |
| 107 | Pyranometer | Y | N | N | Y | N | N | N | N | N | N | N | N |
| 108 | Solar Cell | N | N | N | N | N | N | N | N | N | N | N | N |
| 109 | Piezometer Tube | N | N | N | N | N | N | N | N | N | N | N | N |
| 110 | Mercury In Glass Thermometer | N | N | N | N | N | N | N | N | N | N | N | N |
| 111 | Wet & Dry Bulb Thermometer | N | N | N | N | N | N | N | N | N | N | N | N |
| 112 | Digital Anemometer | Y | N | N | N | N | N | N | N | N | N | N | N |
| 113 | Kipp-ZononSolarimeter | N | N | N | N | N | N | N | N | N | N | N | N |
| 114 | Surya Mapi | N | N | N | N | N | N | N | N | N | N | N | N |
| 115 | Buoyancy Meter | N | N | N | N | N | N | N | N | N | N | N | N |
| 116 | Insolometer | N | N | N | N | N | N | N | N | N | N | N | N |
| 117 | PID Controller | N | N | N | N | N | N | N | N | N | N | N | N |
| 118 | Rotameter | Y | N | N | N | N | N | N | N | N | N | N | N |
| 119 | PROVA (Av M-07) | N | N | N | N | N | N | N | N | N | N | N | N |
| 120 | Tes1333r Solar Meter | N | N | N | N | N | N | N | N | N | N | N | N |
| | Output Variables | | | | | | | | | | | | |
| | 1 General | | | | | | | | | | | | |
| 121 | Bottom Heat Loss | N | N | N | N | N | N | N | N | N | N | N | N |
| 122 | Absorber Plate Mean Temperature | N | N | N | N | N | N | N | N | N | N | N | N |
| 123 | Top Heat Loss | N | N | N | N | N | N | N | N | N | N | N | N |
| 124 | Top Loss Coefficient | N | N | N | N | N | N | N | N | N | N | N | N |
| 125 | Efficiency | Y | N | N | N | N | N | N | Y | N | N | N | Y |
| 126 | Nusslet No. | Y | N | N | N | N | N | N | N | N | N | N | N |
| 127 | Rayleigh No. | Y | N | N | N | N | N | N | N | N | N | N | N |
| 128 | Glass Temperature | N | N | N | N | N | N | N | N | N | N | N | N |
| 129 | Side Heat Loss | N | N | N | N | N | N | N | N | N | N | N | N |
| 130 | Edge Heat Loss | N | N | N | N | N | N | N | N | N | N | N | N |
| 131 | Fluid Temperature Variation Along The Tube | N | N | N | N | N | N | N | N | N | N | N | N |
| 132 | Fluid Outlet And Inlet Temperature Difference | N | N | N | N | N | N | N | N | N | N | N | N |
| 133 | Pressure Drop | N | N | N | N | N | N | N | N | N | N | N | N |
| 134 | Absorber Mean And Ambient Temp. Difference | Y | N | N | N | N | N | N | N | N | N | N | N |
| 135 | Thermal Performance | N | N | N | N | N | N | N | N | N | N | N | N |
| 136 | Useful Energy | N | N | Y | N | N | N | N | Y | N | N | N | N |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 137 | Fluid Outlet Temperature | N | N | Y | N | N | N | N | N | N | N | N | Y |
| 138 | Radiation Loss | N | N | N | N | N | N | N | N | N | N | N | N |
| 139 | Exergetic Efficiency | N | N | N | N | N | N | N | N | N | N | N | N |
| 140 | Tolerable Fluid Inlet Temperature Variation | N | N | N | N | N | N | N | N | N | N | N | N |
| 141 | Tolerable Variation In Temperature Difference Of Outlet And Inlet Temperature | N | N | N | N | N | N | N | N | N | N | N | N |
| 142 | Insulation Temperature | N | N | N | N | N | N | N | N | N | N | N | N |
| 143 | Compare The Results Of Two Dimension And One Dimension Model | N | N | N | N | N | N | N | N | N | N | N | N |
| 144 | Tilt | N | N | N | N | N | N | N | N | N | N | N | N |
| 145 | Collector Area Ratio | N | N | N | N | N | N | N | N | N | N | N | N |
| 146 | Auxiliary Energy | N | N | N | N | N | N | N | N | N | N | N | N |
| 147 | $1^{st}$ Glass Cover Inner Temp. | N | N | N | N | N | N | N | N | N | N | N | N |
| 148 | $1^{st}$ Glass Cover Outer Temp. | N | N | N | N | N | N | N | N | N | N | N | N |
| 149 | $2^{nd}$ Glass Cover Inner Temp. | N | N | N | N | N | N | N | N | N | N | N | N |
| 150 | Top Face Convective Heat Transfer Coefficient | N | N | N | N | N | N | N | N | N | N | N | N |
| 151 | Top Face Radiative Heat Transfer Coefficient | N | N | N | N | N | N | N | N | N | N | N | N |
| 152 | $2^{nd}$ Glass Cover Outer Temp. | N | N | N | N | N | N | N | N | N | N | N | N |
| 153 | Cost | N | N | N | N | N | N | N | N | N | N | N | N |
| | 2 Application | | | | | | | | | | | | |
| | 2.1 Solar Still | | | | | | | | | | | | |
| 154 | Amount Of Water Produced In Still | N | N | N | Y | N | N | N | N | N | N | N | N |
| 155 | Condensed Temperature In Still | N | N | N | N | N | N | N | N | N | N | N | N |
| 156 | Glass Inside Temperature | N | N | N | N | N | N | N | N | N | N | N | N |
| 157 | Water Temperature In Still | N | N | N | N | N | N | N | N | N | N | N | N |
| 158 | Vapor Temp. Produced In Still | N | N | N | N | N | N | N | N | N | N | N | N |
| 159 | Glass Outside Temperature | N | N | N | N | N | N | N | N | N | N | N | N |
| | 2.2 Solar Water Heater | | | | | | | | | | | | |
| 160 | Solar Fraction | N | N | N | N | N | N | Y | N | N | N | N | N |
| 161 | Energetic And Environmental Payback Periods | N | N | N | N | N | N | Y | N | N | N | N | N |
| 162 | Wind Uplift | | | | | | | | | | | | |
| | 2.2.1 Separate | | | | | | | | | | | | |
| | 2.2.1.1 Indirect Type | | | | | | | | | | | | |
| 163 | Service Water Outlet Temperature | N | N | N | N | N | N | N | N | N | N | N | N |
| 164 | Production Cost At Manufacturer Level | N | N | N | N | Y | N | N | N | N | N | N | N |
| 165 | Initial Cost At User Level | N | N | N | N | Y | N | N | N | N | N | N | N |
| 166 | Total Cost | N | N | N | N | Y | N | N | N | N | N | N | N |
| 167 | Cost Comparison | N | N | N | N | Y | N | N | N | N | N | N | N |
| 168 | Cost Saving | N | N | N | N | N | N | N | N | N | N | N | N |
| | 2.2.2 Integrated Heat Exchanger | | | | | | | | | | | | |
| | 2.2.2.1 Indirect Type | | | | | | | | | | | | |
| 169 | Useful Energy | N | N | N | N | N | N | N | N | Y | N | N | N |
| 170 | Exergy Efficiency | N | N | N | N | N | N | N | N | Y | N | N | N |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 171 | Flow Path In The Tank | N | N | N | N | N | N | N | N | N | N | N | N |
| 172 | Velocity Distribution In The Tank | N | N | N | N | N | N | N | N | N | N | N | N |
| 173 | Temperature Of Tank | N | N | N | N | N | N | N | N | N | N | N | N |
| 174 | Service Water Outlet Temperature | N | Y | N | N | N | N | N | N | N | N | N | N |
| 175 | Service Water Flow Rate | N | Y | N | N | N | N | N | N | N | N | N | N |
| 176 | Storage Volume | N | N | N | N | N | N | N | N | N | N | N | N |
| 177 | Performance | N | N | N | N | N | N | N | N | N | N | N | N |
| 178 | Auxiliary Energy | N | N | N | N | N | N | N | N | N | N | N | N |
| | 2.3 Effluent Evaporation System | | | | | | | | | | | | |
| 179 | Evaporation Rate | N | N | N | N | N | N | N | N | N | N | N | N |
| | 2.4 Solar Cooker | | | | | | | | | | | | |
| 180 | Absorber Temperature | N | N | N | N | N | N | N | N | N | N | N | N |
| | 2.5 Heat Pump | | | | | | | | | | | | |
| 181 | Cop | N | N | N | N | N | Y | N | N | N | N | N | N |
| 182 | Efficiency | N | N | N | N | N | Y | N | N | N | N | N | N |
| | 2.6 Solar Geyser Cum Distiller | | | | | | | | | | | | |
| 183 | Storage Temperature | N | N | N | N | N | N | N | N | N | N | N | N |
| 184 | Amount Of Water Produced | N | N | N | N | N | N | N | N | N | N | N | N |
| | 2.7 Water Heater + Space Heating | | | | | | | | | | | | |
| 185 | Solar Fraction | N | N | N | N | N | N | N | N | N | N | N | N |
| | 2.8 Solar Oven | | | | | | | | | | | | |
| 186 | Efficiency | N | N | N | N | N | N | N | N | N | N | N | N |
| | 2.8 Solar Cooling | | | | | | | | | | | | |
| 187 | Cop | N | N | N | N | N | N | N | N | N | N | N | N |
| 188 | Efficiency | N | N | N | N | N | N | N | N | N | N | N | N |
| | Sum | 9 | 13 | 12 | 6 | 14 | 7 | 6 | 2 | 8 | | 4 | 9 |

| Sr. No. | Attributes | Paper | | | Sum |
|---|---|---|---|---|---|
| | | P46 | P47 | P48 | |
| | Input Attributes | | | | |
| | 1. General | | | | |
| | 1.1 Absorber Plate | N | Y | N | |
| 1 | Type Of Absorber | 0 | 0 | 0 | 2 |
| 2 | Absorber Shape | 0 | 0 | 0 | 4 |
| 3 | Micro Capillary Film (MCF) Voidage | 0 | 0 | 0 | 2 |
| 4 | Absorber Area | 0 | 0 | 0 | 4 |
| 5 | Absorber Material | 0 | 0 | 0 | 1 |
| 6 | Absorber Emissivity | 0 | 0 | 0 | 4 |
| 7 | Thermal Conductivity Of Absorber | 0 | 0 | 0 | 2 |
| 8 | Selective Coating Of Absorber | 0 | 0 | 0 | 4 |
| 9 | Absorber Color | 0 | 4 | 0 | 8 |
| | 1.2 Tubes | N | N | N | |
| 10 | Heat Enhancement Devices | 0 | 0 | 0 | 3 |
| 11 | Length Of Tubes | 0 | 0 | 0 | 4 |
| 12 | Number Of Tubes | 0 | 0 | 0 | 5 |

| | | | | | |
|---|---|---|---|---|---|
| 13 | Diameter Of Riser | 0 | 0 | 0 | 4 |
| 14 | Spacing B/W Risers | 0 | 0 | 0 | 6 |
| | 1.3 Transparent Cover | N | N | N | |
| 15 | Cover Material | 0 | 0 | 0 | 2 |
| 16 | Absorptivity Of Cover | 0 | 0 | 0 | 4 |
| 17 | Selective Coating Of Cover | 0 | 0 | 0 | 4 |
| 18 | Transmittance Of Cover | 0 | 0 | 0 | 3 |
| 19 | Number Of Covers | 0 | 0 | 0 | 8 |
| 20 | Optical Efficiency | 0 | 0 | 0 | 2 |
| 21 | Reflectance Of Cover | 0 | 0 | 0 | 3 |
| 22 | Cover Thickness | 0 | 0 | 0 | 2 |
| | 3. Operational | N | Y | N | |
| 23 | Tilt | 0 | 0 | 0 | 18 |
| 24 | Flow Rate | 0 | 0 | 0 | 33 |
| 25 | Fluid Inlet Temp. | 0 | 3 | 0 | 40 |
| 26 | Fix To Wall | 0 | 0 | 0 | 3 |
| | 4. Environment | Y | Y | N | |
| 27 | Solar Irradiation | 0 | 0 | 0 | 71 |
| 28 | Wind Velocity | 2 | 0 | 0 | 20 |
| 29 | Ambient Temp. | 0 | 3 | 0 | 41 |
| | 2 Others | Y | N | Y | |
| 30 | Type Of Fluid | 0 | 0 | 0 | 7 |
| 31 | Fluid Concentration | 0 | 0 | 0 | 4 |
| 32 | Specific Heat Of Fluid | 0 | 0 | 0 | 1 |
| 33 | Phase Changing Material | 0 | 0 | 0 | 4 |
| 34 | Tracking | 0 | 0 | 0 | 7 |
| 35 | Type Of Conditions B/W Absorber Plate & Glass Cover (Vacuum) | 0 | 0 | 0 | 3 |
| 36 | Different Arrangements Of Honey Comb Materials | 0 | 0 | 0 | 2 |
| 37 | Distance B/W Absorber Plate & Honey Comb Material | 0 | 0 | 0 | 3 |
| 38 | Distance B/W Transparent Cover & Honey Comb Material | 0 | 0 | 0 | 3 |
| 39 | Insulation Material | 0 | 0 | 2 | 4 |
| 40 | Thermal Capacitance Of All Components | 0 | 0 | 0 | 3 |
| 41 | Collector Aging | 0 | 0 | 0 | 3 |
| 42 | Hour Angle | 0 | 0 | 0 | 4 |
| 43 | Declination Angle | 0 | 0 | 0 | 6 |
| 44 | Latitude | 0 | 0 | 0 | 7 |
| 45 | Roof Azimuthal Angle | 0 | 0 | 0 | 4 |
| 46 | Roof Tilt Angle | 0 | 0 | 0 | 4 |
| 47 | Location | 0 | 0 | 0 | 4 |
| 48 | Efficiency | 0 | 0 | 0 | 2 |
| 49 | Wind Heat Transfer Coefficient | 0 | 0 | 0 | 3 |
| 50 | Absorber Plate Temperature | 0 | 0 | 0 | 5 |
| 51 | Azimuthal Angle | 0 | 0 | 0 | 2 |
| 52 | Incidence Angle | 0 | 0 | 0 | 4 |
| 53 | Radiation Loss | 0 | 0 | 0 | 3 |
| 54 | Date | 0 | 0 | 0 | 2 |
| 55 | Time | 0 | 0 | 0 | 5 |
| 56 | Deviation In Inlet Fluid Temperature | 0 | 0 | 0 | 0 |
| 57 | Guide Plate | 2 | 0 | 0 | 2 |
| 58 | Collector Lifting | 2 | 0 | 0 | 2 |
| 59 | Fluid Flow Stoppage | 0 | 0 | 1 | 1 |

| | | | | | |
|---|---|---|---|---|---|
| | 5. Application | N | N | N | |
| | 5.1 Effluent Evaporation System | N | N | N | |
| 60 | Concentration Of Effluent | 0 | 0 | 0 | 4 |
| 61 | Relative Humidity | 0 | 0 | 0 | 4 |
| | 5.2 Solar Still | N | N | N | |
| 62 | Water Depth | 0 | 0 | 0 | 7 |
| 63 | Direction | 0 | 0 | 0 | 4 |
| 64 | Type Of Water | 0 | 0 | 0 | 2 |
| 65 | Operating Mode | 0 | 0 | 0 | 3 |
| | 5.3 Solar Water Heater | Y | N | N | |
| 66 | Type Of Auxiliary Heater | 0 | 0 | 0 | 4 |
| | 5.3.1 Separate | N | N | N | |
| | 5.3.1.1 Indirect Type | N | N | N | |
| | Application | N | N | N | |
| 67 | Material Cost | 0 | 0 | 0 | 3 |
| 68 | Operation & Maintenance Cost | 0 | 0 | 0 | 4 |
| 69 | Others Cost | 0 | 0 | 0 | 2 |
| 70 | Interest Rate | 0 | 0 | 0 | 3 |
| 71 | Inflation Rate | 0 | 0 | 0 | 2 |
| | 5.3.2 Integrated | N | N | N | |
| | 5.3.2.1 Indirect Type | N | N | N | |
| 72 | Recirculation Rate | 0 | 0 | 0 | 3 |
| 73 | Heat Exchanger Tube Diameter | 0 | 0 | 0 | 3 |
| 74 | Distance From Tank Walls | 0 | 0 | 0 | 4 |
| 75 | Length Of Heat Exchanger | 0 | 0 | 0 | 3 |
| | 5.4 Solar Cooker | N | N | N | |
| | 5.5 Solar Geyser Cum Distiller | N | N | N | |
| | 5.6 Solar Oven | N | N | N | |
| | 5.7 Heat Pump | N | N | N | |
| 76 | Condenser Temp. | 0 | 0 | 0 | 2 |
| 77 | Medium Fluid Evaporator Temp. | 0 | 0 | 0 | 2 |
| | 5.8 Solar Cooling System | N | N | N | |
| | 5.9 Water Heater + Space Heating | N | N | N | |
| | 6. Theoretical | N | Y | Y | |
| 78 | Energetic Prospective | N | N | N | |
| 79 | Economic Prospective | N | N | N | |
| 80 | Environment Prospective | N | N | N | |
| 81 | Sensitivity Analysis (Regression Analysis) | N | N | N | |
| 82 | FVM | N | N | N | |
| 83 | Evaluate The Effect Of Glass Absorptivity On The System Performance | N | N | N | |
| 84 | One Dimension Heat Eqn. | N | N | N | |
| 85 | Two Dimension Heat Eqn. | N | N | N | |
| 86 | Two Dimensional Finite Element Model | N | N | N | |
| 87 | Neural Network | N | N | N | |
| 88 | Adaptive-Network- Based Fuzzy Inference System (ANFIS) | N | N | N | |
| 89 | Support Vector Machines (SVM) | N | N | N | |
| 90 | Mathematical Model | N | N | N | |
| 91 | Exergy Analysis | N | N | N | |

| | | | | | |
|---|---|---|---|---|---|
| 92 | Temp | N | N | N | |
| 93 | TOMP | N | N | N | |
| 94 | FDM | N | N | N | |
| | 7.Experimental | Y | Y | Y | |
| 95 | Validation Of Models Of Radiation Calculation | N | N | N | |
| | 8. Simulation | N | N | N | |
| 96 | CFD | N | N | N | |
| 97 | TRNSYS | N | N | N | |
| 98 | TRNFLOW | N | N | N | |
| 99 | MATLAB | N | N | N | |
| 100 | MINSUN | N | N | N | |
| 101 | WATSUN | N | N | N | |
| 102 | KOLEKTOR 2.2 | N | N | N | |
| 103 | ANSYS | N | N | N | |
| | 9. Review | N | N | N | |
| 104 | Thermotropic Layers | N | N | N | |
| | 10. Instruments | N | N | N | |
| 105 | Thermocouple | N | N | N | |
| 106 | Millivoltmeter | N | N | N | |
| 107 | Pyranometer | N | N | N | |
| 108 | Solar Cell | N | N | N | |
| 109 | Piezometer Tube | N | N | N | |
| 110 | Mercury In Glass Thermometer | N | N | N | |
| 111 | Wet & Dry Bulb Thermometer | N | N | N | |
| 112 | Digital Anemometer | N | N | N | |
| 113 | Kipp-ZononSolarimeter | N | N | N | |
| 114 | Surya Mapi | N | N | N | |
| 115 | Buoyancy Meter | N | N | N | |
| 116 | Insolometer | N | N | N | |
| 117 | PID Controller | N | N | N | |
| 118 | Rotameter | N | N | N | |
| 119 | PROVA (Av M-07) | N | N | N | |
| 120 | Tes1333r Solar Meter | N | N | N | |
| | Output Variables | | | | |
| | 1 General | | | | |
| 121 | Bottom Heat Loss | N | N | N | |
| 122 | Absorber Plate Mean Temperature | N | N | Y | |
| 123 | Top Heat Loss | N | N | N | |
| 124 | Top Loss Coefficient | N | N | N | |
| 125 | Efficiency | N | Y | N | |
| 126 | Nusslet No. | N | N | N | |
| 127 | Rayleigh No. | N | N | N | |
| 128 | Glass Temperature | N | N | N | |
| 129 | Side Heat Loss | N | N | N | |
| 130 | Edge Heat Loss | N | N | N | |
| 131 | Fluid Temperature Variation Along The Tube | N | N | N | |
| 132 | Fluid Outlet And Inlet Temperature Difference | N | N | N | |
| 133 | Pressure Drop | N | N | N | |
| 134 | Absorber Mean And Ambient Temp. Difference | N | N | N | |
| 135 | Thermal Performance | N | N | N | |

| | | | | | |
|---|---|---|---|---|---|
| 136 | Useful Energy | N | N | N | |
| 137 | Fluid Outlet Temperature | N | N | N | |
| 138 | Radiation Loss | N | N | N | |
| 139 | Exergetic Efficiency | N | N | N | |
| 140 | Tolerable Fluid Inlet Temperature Variation | N | N | N | |
| 141 | Tolerable Variation In Temperature Difference Of Outlet And Inlet Temperature | N | N | N | |
| 142 | Insulation Temperature | N | N | N | |
| 143 | Compare The Results Of Two Dimension And One Dimension Model | N | N | N | |
| 144 | Tilt | N | N | N | |
| 145 | Collector Area Ratio | N | N | N | |
| 146 | Auxiliary Energy | N | N | N | |
| 147 | 1st Glass Cover Inner Temp. | N | N | N | |
| 148 | 1st Glass Cover Outer Temp. | N | N | N | |
| 149 | 2nd Glass Cover Inner Temp. | N | N | N | |
| 150 | Top Face Convective Heat Transfer Coefficient | N | N | N | |
| 151 | Top Face Radiative Heat Transfer Coefficient | N | N | N | |
| 152 | 2nd Glass Cover Outer Temp. | N | N | N | |
| 153 | Cost | N | N | N | |
| | 2 Application | | | | |
| | 2.1 Solar Still | | | | |
| 154 | Amount Of Water Produced In Still | N | N | N | |
| 155 | Condensed Temperature In Still | N | N | N | |
| 156 | Glass Inside Temperature | N | N | N | |
| 157 | Water Temperature In Still | N | N | N | |
| 158 | Vapor Temp. Produced In Still | N | N | N | |
| 159 | Glass Outside Temperature | N | N | N | |
| | 2.2 Solar Water Heater | | | | |
| 160 | Solar Fraction | N | N | N | |
| 161 | Energetic And Environmental Payback Periods | N | N | N | |
| 162 | Wind Uplift | | | | |
| | 2.2.1 Separate | | | | |
| | 2.2.1.1 Indirect Type | | | | |
| 163 | Service Water Outlet Temperature | N | N | N | |
| 164 | Production Cost At Manufacturer Level | N | N | N | |
| 165 | Initial Cost At User Level | N | N | N | |
| 166 | Total Cost | N | N | N | |
| 167 | Cost Comparison | N | N | N | |
| 168 | Cost Saving | N | N | N | |
| | 2.2.2 Integrated Heat Exchanger | | | | |
| | 2.2.2.1 Indirect Type | | | | |
| 169 | Useful Energy | N | N | N | |
| 170 | Exergy Efficiency | N | N | N | |
| 171 | Flow Path In The Tank | N | N | N | |
| 172 | Velocity Distribution In The Tank | N | N | N | |
| 173 | Temperature Of Tank | N | N | N | |
| 174 | Service Water Outlet Temperature | N | N | N | |
| 175 | Service Water Flow Rate | N | N | N | |
| 176 | Storage Volume | N | N | N | |
| 177 | Performance | N | N | N | |

| | | | | | |
|---|---|---|---|---|---|
| 178 | Auxiliary Energy | N | N | N | |
| | 2.3 Effluent Evaporation System | | | | |
| 179 | Evaporation Rate | N | N | N | |
| | 2.4 Solar Cooker | | | | |
| 180 | Absorber Temperature | N | N | N | |
| | 2.5 Heat Pump | | | | |
| 181 | Cop | N | N | N | |
| 182 | Efficiency | N | N | N | |
| | 2.6 Solar Geyser Cum Distiller | | | | |
| 183 | Storage Temperature | N | N | N | |
| 184 | Amount Of Water Produced | N | N | N | |
| | 2.7 Water Heater + Space Heating | | | | |
| 185 | Solar Fraction | N | N | N | |
| | 2.8 Solar Oven | | | | |
| 186 | Efficiency | N | N | N | |
| | 2.8 Solar Cooling | | | | |
| 187 | Cop | N | N | N | |
| 188 | Efficiency | N | N | N | |
| | Sum | 6 | 10 | 3 | |

Fig.2.11 IM for FPLSC

In fig.2.11 P1 is represented by [14], P2 is represented by [15]; similarly P48 is represented by [61].

### 2.5.5.4.1 Information get from the IM for FPLSC is:

The performance of a FPLSC is influenced by the environment variables, these variables cannot be controlled so the accurate effect of these variables on FPLSC needs to be described. The values of environment variables are rapidly changing with time and location so these things make it more necessary to find the effect on FPLSC performance. From the IM, it is observed that ambient temperature, solar irradiation and wind velocity are main environment attributes used to evaluate FPLSC performance by many researchers.

Performance of the system is described with the operating conditions under which it works. From the IM of FPLSC, the various operating parameters are collected which are used to vary and see the performance of collector. Operating parameters those are found from IM are type of fluid used, fluid inlet temperature, flow rate, integrated to the building or separate and amount of tilt.

Information about different type of applications or uses of the FPLSC like FPLSC assisted solar still, solar heat pump, solar cooling system, effluent evaporation system, solar geyser cum distiller, solar oven, solar water heater, solar cooker. This information is helpful in widen the area of thinking of the industrialist about FPLSC to use it in different applications of the industry. The important parameters used in these applications are also collected. Like in solar still water depth is the important parameter for optimum water production, in solar water heater type of heat exchanger, amount of hot water required, and storage tank dimensions. Papers relating to the particular application are easily sorted out from the IM for to get more information about the application.

Information about the type of outputs used to evaluate the collector performance used by researchers is collected in IM, which is helpful to new researcher who wants to do some research on the collector. The main outputs that most of researchers concerns about are absorber plate temperature, useful energy collected by fluid, efficiency and outlet water temperature.

A number of different approaches like one dimension heat transfer equations, two dimension heat transfer heat transfer equations, Neural Network, FDM, mathematical models, TOMP etc. used to evaluate the performance of collector are collected in the IM.It creates flexibility to evaluate the collector. Papers are easily collected from the matrix those are used these approaches.

Information about the papers in which mathematical models are developed for FPLSC evaluation is easily found from the IM if someone wants to find these papers.

A Researcher does some simulation or theoretical work and wants to compare the output with the experimental results for the authentication of the work. Information about the papers in which experimental work is done collected from the IM of FPLSC, so researcher finds the papers easily in which experimental work is done with the help of this matrix to get the experimental results.

Many softwares those are used to evaluate the FPLSC collector are collected in the IM. It creates flexibility to adopt suitable software for evaluation of the collector. For more information about the implementation of the software, paper which used this software easily found from the IM.

A list of instruments that are used in experimental setup of FPLSC and its applications also collected in IM so if someone does some experiment get information about the type of measuring instruments used in the setup.

The information about the design parameters those affects the performance of FPLSC are collected in the IM. This make designer to know the attributes those are considered more while designing.

As discussed in section 2.5.4. 1 about the calculation of total work done on particular attribute and in particular paper, sigma forms at the right and bottom of the IM gives this information. From the IM for FPLSC it is found that there is very less work done on the application of solar cooling system and heat pump so these are the applications which are needed to be exploited more. FPLSC assisted solar still and solar water heater are the main applications those are studied by many researchers.

This IM is useful for to find the gap in the research field. This information is useful for the new researcher to get the gap easily for further research. A comprehensive and exhaustive cause and effect diagram develops for performance of FPLSC as shown in Fig.2.11. Different causes to the performance of FPLSC are shown in fig 2.12. Gaps are found by comparing the information from the cause and effect diagram and IM for FPLSC.

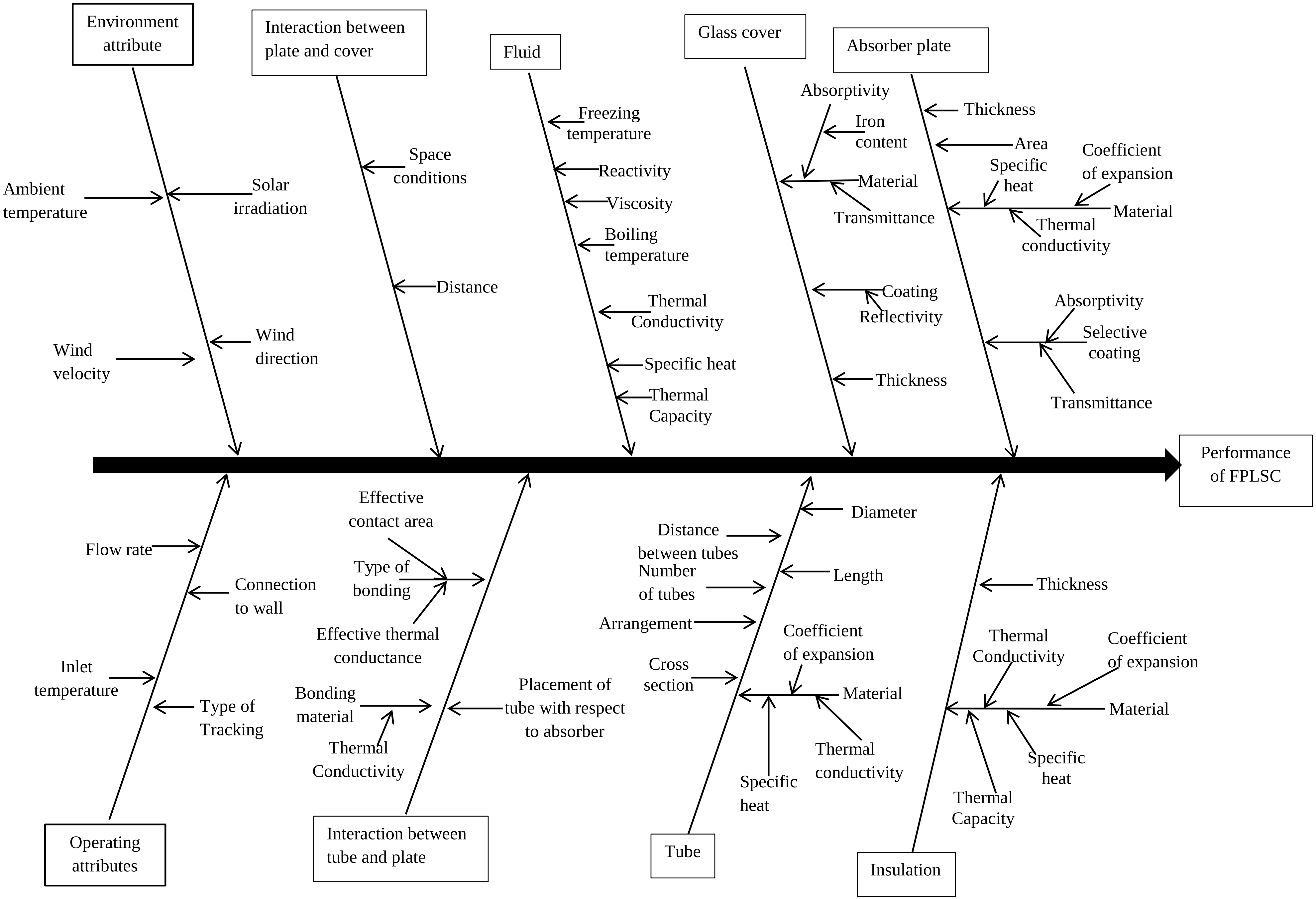


Fig 2.12 Cause and effect diagram for the Performance of FPLSC

From the cause and effect diagram, it is found that bonding between absorber plate and tubes affects the performance of collector by different causes like effective thermal conductance, effective contact area for heat flow from the absorber plate to the tubes. But from the IM of FPLSC, it is found that no work is done on these attributes to see the influence on FPLSC.

There is no work done to see the effect of placement of tubes with respect to the absorber plate on the FPLSC performance as per the information from the IM for FPLSC.

No work is done to see the effect on performance of FPLSC by varying the thickness of tube. Thickness of the tube is minimum be the favorable condition for better performance. In case thin tube is not available in local market. So to make decision about whether the thick tube is used or it is necessary to get the thin tube from the distant market, the information about the effect on performance of FPLSC with the tube thickness is necessary. Similar is the case with absorber thickness.

Effect of fluid reactivity on the performance of the collector components like risers, headers, circulating pump etc. are not studied yet. Due to impurities in the fluid or by its own properties it reacts with the tubes material or corrodes the tubes which degrades the tube performance. So it is necessary to evaluate the effect of reactivity on collector.

### 2.5.6 **Step by step procedure**

As this type of methodology is useful in other research fields so the step by step procedure of the methodology given below:

1. Collect the research papers about the particular research filed.
2. Find the attributes studied in the research papers.
3. Make IM between research paper and attributes.
4. Make cause and affect diagram form the attributes as per the area of interest for e.g. performance, cost etc. to see the attributes effect that area in more efficient way. This diagram with the use of information from IM helps in finding the gap points.
5. Spider graph useful to evaluate the papers of interest.
6. Row totals, column totals and other different techniques as discussed in section 2.5 useful to develop knowledge from IM.

For better understanding of the methodology the graphical representation of the methodology is shown in fig 2.13.

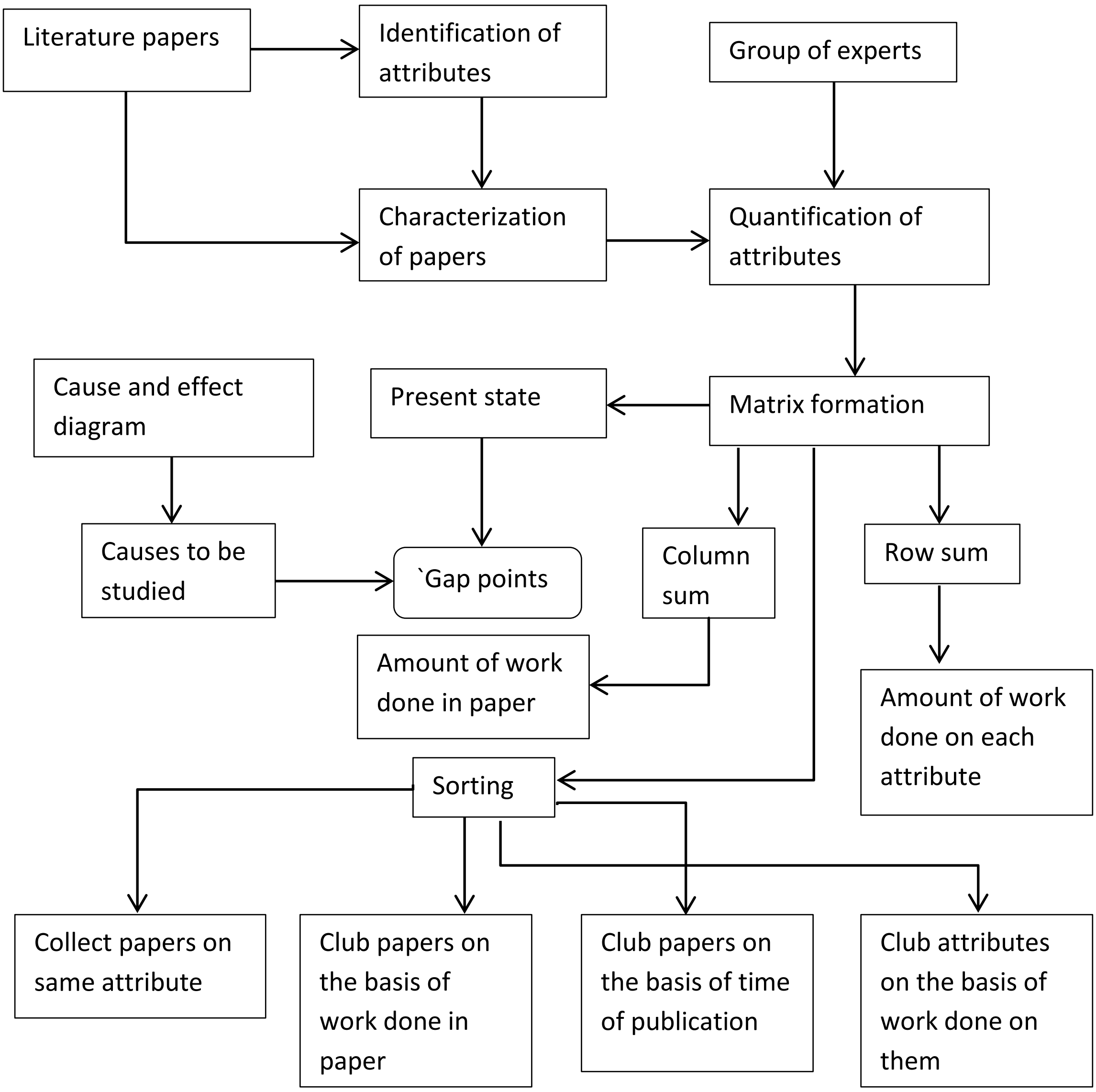


Fig.2.13 Graphical representation of Methodology

A new approach of literature review of FPLSC is proposed which is very useful for the researchers, industrialists, manufacturers, designers. In this IM is formed from the information available in the different publication data. The amount of research work done on each individual attribute also clearly calculated from the IM, with the help of which the gap analysis is carried out efficiently and effectively. Also from the matrix papers related to the particular attributes are sorted out and get the information about those particular attributes. Spider graph is useful tool to get the more suitable paper of interest on the basis of attributes. With this attribute based literature review the knowledge related to performance, design and manufacturing is easily obtained from the IM. This IM is a permanent source of knowledge and need to be updated so that anyone takes more benefit from this database.

**Gap analysis**

There are number of parameters on which the performance of the system depends like environment variables, operating conditions, design variables and component materials.

There are models only for the thermal performance of the FPLSC. There is a need to develop the model which is useful to analyze the different properties of FPLSC not only thermal performance for the FPLSC optimization. As the any property of the system is the overall performance of its constituents and the interaction between the constituents. So there is a need of model to represents all constituents and the interaction between the constituents for the different analysis of the collector. There are number of applications of FPLSC are studied in the research papers and evaluate the performance of the overall system. The performance of the FPLSC also depends on the type of application for which it is used. So the type of application for which FPLSC is used effect the selection of the system. There is lot of models and techniques are developed to evaluate the thermal performance of the FPLSC system. But there is no work is found for the selection of optimum FPLSC system for a given application in the available literature. Only thermal efficiency is not the criteria to select a particular system. There are number of other factors are also concerned like reliability, quality, cost etc. So there is a need of information about the factors effecting FPLSC selection and the technique through which optimum FPLSC system is selected by considering all these factors.

A number of FPLSC systems are available in the market for same and different applications. Selection of optimal FPLSC depends on a number of attributes like performance of FPLSC which depends on design, environmental, position on earth, operating attributes, solar irradiation and type of application. Other parameters those are also considered for optimal selection is cost of the system, durability, availability, reliability of the system etc. A multi attribute based selection and evaluation procedure is developed for FPLSC to get the optimal system as per the requirements of the user.

### 3.1 Attributes identification for FPLSC selection:

A number of attributes are collected relating to the FPLSC system those are able to find optimum FPLSC system. Cause and effect diagram is developed as shown in fig.3.1 to identify the attributes for the selection of FPLSC.

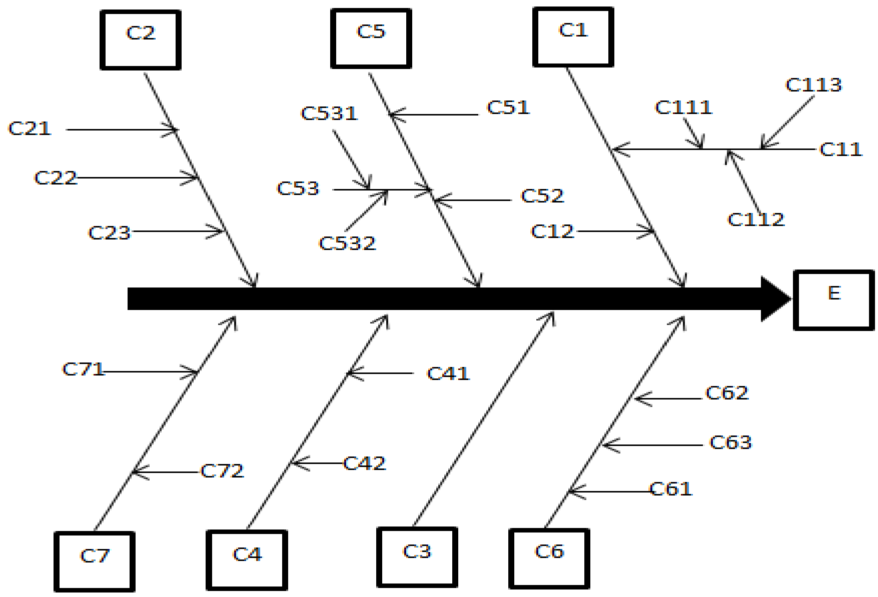


Fig 3.1 Cause and Effect diagram for the selection of FPLSC

Here, E-Selection of FPLSC , C1-Components, C11-Material, C111-Chemical Properties, C112-Thermal Properties, C113-Mechanical Properties, C12-Design Parameters , C2-Performance, C22-Output, C21-Efficiency, C23-Performance Constraints, C3-General Information, C4-Environment Attributes, C41-Effect on Performance, C42-Effect on Reliability, C5-Reliability, C51-Design Life, C52-Warranty, C53-Maintenance, C531-Frequency, C532-Level of Maintenance, C6-Cost, C61-Initial Cost, C62-Operating Cost, C63-Maintenance Cost, C7-Operational Attributes, C71-Given Attributes, C72-Site dependent Attributes.

I. Material selection for different components

Material properties of different components those are govern the thermal performance of the system are described below.

1. Absorber plate material (M1)

   Specific heat value(A1), Thermal conductivity(A2), Emissivity (A3), Reactivity to the environment variables (A4), Maximum working temperature (A5), Thermal expansion coefficient (A6) and Variation in properties with temperature (A7).

2. Selective coating for absorber (M2)

   Absorptivity to high frequency radiations(A8), Thermal conductivity (A9), emissivity (A10), maximum working temperature (A11) and variation in properties with temperature (A12).

3. Flow tube material (M3)

   Specific heat value (A13), thermal conductivity (A14), reactivity to the environment variables (A15), maximum working temperature (A16), thermal expansion coefficient (A17), variation in properties with temperature (A18), reactivity to heat carrying fluid (A19).

4. Transparent cover material (M4)

   Maximum working temperature (A20), variation in properties with temperature (A21), transmittance to high frequency radiations (A22), transmittance to low frequency radiations (A23), reflectivity (A24). Absorptivity and reflectivity depend on the amount of iron and carbon content present in case of glass.

5. Selective coating of transparent cover (M5)

   Transmittance to high frequency radiations (A25), variation in properties with temperature (A26), maximum working temperature (A27) and reactivity to the environment variables (A28).

6. Insulation material (M6)

   Specific heat value (A29), thermal conductivity (A30), variation in properties with temperature (A31), thermal expansion coefficient (A32), maximum working temperature (A33).

7. Casing material (M7)

Reactivity to the environment variables (A34), maximum working temperature (A35), thermal conductivity (A36) and thermal expansion coefficient (A37).

8. Bonding material (M8)

   Specific heat value (A38), thermal conductivity (A39), maximum working temperature (A40), thermal expansion coefficient (A41) and variation in properties with temperature (A42).

9. Fluid (M9)

   Type of fluid (A43), Thermal conductivity of fluid (A44), Freezing point temperature of fluid (A45), Boiling point temperature of fluid (A46), Specific heat capacity of fluid (A47), Latent heat value of fluid (A48), Viscosity (A49).

The individual property of the material cannot be improved for to improve performance. So performance is improved by selecting the material which has all the desired properties in the acceptable range. Like Cu is the best candidate for absorber plate and flow tube manufacturing because of its properties satisfies the desired requirements.

II. Design attributes those are effecting the system performance are:

10. Absorber

    Absorber area (M10), Absorber shape (M11), Absorber thickness (M12).

11. Flow tube

    Diameter of tubes carrying heat transfer fluid (M13), Tube length (M14), Type of tube arrangement (M15), Flow tube cross section (M16), Tube spacing (M67).

12. Transparent cover

    Transparent cover thickness (M17)

13. Insulation

    Back Insulation thickness (M18), back density (M63), Side density (M64), Side insulation thickness (M65)

14. Interaction between absorber and glass cover

    Distance between absorber plate and glass cover (M19), Vacuum or ambient conditions between absorber plate & glass cover (M20)

15. Bonding

    Type of bonding between absorber plate & flow tube (M21)

16. Casing

    Thickness of casing (M22)

III. Stand of FPLSC

Material (M23), Flexibility (M24), Ease of setup (M25).

IV. Cost

Initial cost (M26), Maintenance cost (M27), Transportation cost (M28), operating cost (M29).

V. Reliability

Warranty (M30), Design life (M32), frequency of maintenance (M33), Maintenance level (M34).

VI. Performance

Solar fraction (M35), Efficiency (M36), Output temperature (M37), Pumping power (M38), stagnation temperature (M39), maximum operating temperature (M40), maximum operating pressure (M41), maximum flow rate (M42), optical efficiency (M43), Useful energy (M44).

VII. Operation

Inlet temperature (M45), Tracking (fixed, continuous, discrete) (M46), Type of tracking system (M47), Flow rate range (M48), Type of high pressure safety device (M49), Type of high temperature safety device (M50), Type of freezing protection (M51), Type of application (M52), Working Pressure range (M53), Open or closed cycle (M54), Natural or pumped flow (M55), Working temperature range (M56), Type of pumping system (M57).

VIII. Interaction between absorber and tubes

Placement of tubes with respect to absorber (M58), riser tube thickness (M59), Header diameter (M60), Header thickness (M61), absorber and tube arrangement (M66)

IX. Others

Weight (M62).

There are 111 attributes are collected to describe the FPLSC. This attribute based exhaustive database helps in more precise classification of different FPLSC systems. This information helps user for the selection of optimal FPLSC. The following example illustrates how FPLSC system is characterized in terms of attributes. Attributes those are given by the manufacturer are put in the table3.1.

Table 3.1
Attributes based Classification of FKT-1s Portrait manufactured by Bosch solar thermal

| Sr. No. | Attribute | Description |
|---|---|---|
| 1 | M1 | Cu |
| 2 | M2 | Highly selective PVD |
| 3 | A8 | 95%±2% |
| 4 | A10 | 5%±2% |

| | | |
|---|---|---|
| 5 | M3 | Cu |
| 6 | M4 | Glass |
| 7 | A22 | 91.5% |
| 8 | M6 | Mineral wool |
| 9 | M7 | Fiber glass |
| 10 | M8 | Cu |
| 11 | M10 | 2.41 $m^2$ |
| 12 | M17 | 3.2 mm |
| 13 | M18 | 55 mm |
| 14 | M21 | Ultrasonic welding |
| 15 | M39 | $188^0$C |
| 16 | M40 | $120^0$C |
| 17 | M41 | 10 bar |
| 18 | M42 | 50 L/hr |
| 19 | M62 | 44 kg |

There are only 19 attributes of those information is given by the manufacturer. So the information given by the manufacturer is less for overall description of the system.

**3.2 n- digit coding scheme for the quantification of attributes:**

This attribute based characterization just gives the exhaustive database that is needed to be considered for selection and classification. FPLSC systems are compared, evaluated and ranked by converting this information into useful form. An n- digit coding scheme is developed for this purpose. There are two types of attributes quantitative and qualitative. Qualitative attribute is either converted into quantitative form using a grade scale as shown in table 3.2 or an alpha numeric code is assigned. Quantitative attributes are simply assigned numerical values of those attributes as shown in table 3.3.In case of qualitative attributes, there is a need of exhaustive and comprehensive knowledge about the attribute alternatives available in the market for the proper scaling of alternatives. As the new alternatives are developed day by day, so the scaling of alternatives is also updated with time. Thus this procedure is flexible to the change in alternatives with time. Table 3.4 illustrates the coding of FPLSC based on n-digit coding scheme.

Table 3.2
Coding of absorber material (Qualitative attribute)

| System | Absorber Material | Code |
|---|---|---|
| 1 | Copper (Cu) | 5 |
| 2 | Aluminum (Al) | 4 |
| 3 | Steel (S) | 3 |
| 4 | Plastic (P) | 1 |

Table 3.3
Coding of Absorber area (Quantitative attribute)

| System | Absorber area ($m^2$) | Code |
|---|---|---|
| 1 | 2 | 2 |
| 2 | 2.5 | 2.5 |
| 3 | 2.3 | 2.3 |
| 4 | 3 | 3 |
| 5 | 1.5 | 1.5 |

Table 3.4
Coding of FKT-1s Portrait attributes

| Sr. No. | Attribute | Description | Coding |
|---|---|---|---|
| 1 | M1 | Cu | 5 |
| 2 | M2 | Highly selective PVD | PVD |
| 3 | A8 | 95%±2% | 95 |
| 4 | A10 | 5%±2% | 5 |
| 5 | M3 | Cu | 5 |
| 6 | M4 | Glass | 5 |
| 7 | A22 | 91.5% | 91 |
| 8 | M6 | Mineral Wool | MW |
| 9 | M7 | Fiber Glass | FG |
| 10 | M8 | Cu | 5 |
| 11 | M10 | 2.41 $m^2$ | 2.41 |
| 12 | M17 | 3.2 mm | 3.2 |
| 13 | M18 | 55 mm | 55 |
| 14 | M21 | Ultrasonic welding | 5 |
| 15 | M39 | $188^0$C | 188 |
| 16 | M40 | $120^0$C | 120 |
| 17 | M41 | 10 bar | 10 |
| 18 | M42 | 50 L/hr | 50 |
| 19 | M62 | 44 kg | 44 |

Information developed from the quantification of attributes is very useful to manufacturer, user and designer. From the coding scheme manufacturer gets the idea about the trend of the market. Get the information about the different types of components are used and their corresponding level of quality from the coding scheme. Get the Information about the different parameters that are used for the selection of the FPLSC so that these attributes are concern more while manufacturing. There are number of attributes are collected for the selection of FPLSC; designer uses this information to develop a number of alternate designs at conceptual stage. The information comes from coding helps in making the rough idea about the ranking of these systems. Coding of attributes helps the user to identify the strength and weakness of different attributes of FPLSC, so that the user selects the suitable system as per the requirement.

## 3.3 The Three – stage selection procedure

### 3.3.1 Elimination search (Stage 1)

There are number of attributes are collected to define the system. It is very tedious task to select a suitable system taking into consideration of all these attributes. Identification of a limited number of attributes is necessary; those are effect the system selection directly. The threshold values to these limited attributes can be assigned by obtaining information from the user and group of experts. Hence forth the paper will focus solely on these limited attributes, leaving out the rest. On the basis of threshold values of these listed attributes, a large list of available FPLSC alternatives can be converged to a shortlist. To achieve this, the database is scanned for the listed attributes, one at a time, and the FPLSC attributes with one or more listed attributes falling short of the minimum required (threshold) values for selection are eliminated. This decrease the computational time by narrow down the selection process considerably.

### 3.3.2. Evaluation procedure (Stage 2)

A shortlist of FPLSC alternatives formed in step 1 have to be further filtered to find out the best solution out of all i.e. an optimal FPLSC. Hence these available alternatives FPLSC are ranked in order of preference to select an optimal one.

#### 3.3.2.1 Decision matrix

Firstly all of the information available from the mini database about these satisfying alternatives is represented in the matrix form. This matrix is termed as decision matrix, '**D**'. Each row of the matrix is allocated to one alternative FPLSC and each column to one attribute. Therefore an element $d_{ij}$ of the decision matrix, '**D**' represents the value of $j^{th}$ attribute in non-normalized form/units, corresponding to $i^{th}$ alternative. Thus if there are 'm' short-listed alternatives with 'n' short listed attributes, the decision matrix is an m x n matrix.

#### 3.3.2.2 Normalized matrix

As the elements in each column of matrix, '**D**' has different units and scales, it is necessary to normalize their values. Thus normalized matrix, '**N**' is constructed to have the dimensionless magnitudes of all the attributes of FPLSC on common scale of 0 to 1, which allows the comparison across the attributes. Each element $n_{ij}$ of the normalized matrix, '**N**' can be calculated as

$$n_{ij} = \frac{d_{ij}}{\sqrt[2]{\sum_{i=1}^{m} {d_{ij}}^2}} \qquad (4)$$

Here $d_{ij}$ is an element of the decision matrix, '**D**'.

**3.3.2.3. Relative importance matrix**

The relative importance matrix **'R'** of size n x n is formed to incorporate the relative importance of the attributes over other for a given application. An element $r_{ij}$ of matrix '**R**' represents the relative importance of the $i^{th}$ attribute over the $j^{th}$ attribute and is defined as

$$r_{ij} = \text{Importance of } i^{th} \text{ attribute/importance of } j^{th} \text{ attribute} \qquad (5)$$

The relative importance of one attribute with respect to another for a given application can be obtained from the user or the group of experts specialized in a particular application. The information about the pair-wise comparison of attributes for a particular application is stored in this relative importance matrix '**R**', with all its diagonal elements as unity.

3.3.2.4. **Eigen value formulation and Weight matrix**

Due to human inconsistencies, the information stored in the '**R**' matrix on a pair-wise basis cannot be used directly. It must be modified into a form that gives the relative weights of all attributes taken together so that the sum of all the weight is equal to unity. Thus eigen value formulation is used to find weight vector matrix, '**W**' and is expressed as

$$R\ W = \lambda\ W \qquad (6)$$

Where $W = \{w_1, w_2, w_3 \ldots\ldots w_n\}^T$, and $\lambda$ is the eigen value.

Eq. (6) can be expressed as: $(R - \lambda\ I)W = 0$ (7)

To avoid the trivial solution, we have: $\det(R - \lambda\ I) = 0$ (8)

The solution of Eq. (8) gives the set of 'n' eigen values ($\lambda_1, \lambda_2, \ldots, \lambda_n$). The solution of Eq. (9) for the maximum eigen value '$\lambda_{max}$' gives the weight matrix, '**W**' and the expression is given as

$(R - \lambda maxI)W = 0$ (9)

3.3.2.5. **Weighted normalized decision matrix**

In this step the weighted normalized decision matrix, '**V**'is obtained by incorporating the information stored in the weight matrix, '**W**' into the normalized matrix, '**N**'. A true comparable value of each attribute is given by this weighted normalized matrix and is defined as

$V = [v_{i\,j}]$, where $v_{i\,j} = w_j\, n_{i\,j}$, (10)

Where I = 1, 2,…., m; j = 1,2,….,n

3.3.3. **Ranking of different systems**

There are three techniques are discussed to evaluate the system using information from weighted normalize matrix, TOPSIS approach, Line graph, Spider graph technique.

**3.3.3.1. Technique of order preference by similarity to ideal solution (TOPSIS) approach**

**3.3.3.1.1. Hypothetical best and worst solution**

The hypothetical best solution (HBS) and hypothetical worst solution (HWS) are determined by choosing the maximum and minimum values of attributes from '**V**' matrix as

HBS = $A^* = v_{i\,j\,max}$, when high value is the criteria, or
$= v_{i\,j\,min}$ when low value is the criteria (11)

HWS = $A^{-} = v_{i\,j\,min}$, when high value is the criteria, or
$=v_{i\,j\,max}$, when low value is the criteria (12)

Where I = 1,2,…,m and j = 1,2,…,n. Hence,

$A^* = (V_1^*, V_2^*, \ldots, V_n^*)$

$A^{-} = (V_1^-, V_2^-, \ldots, V_n^-)$

HBS is the combination of best possible alternatives of selected attributes those are available in market. This is very much feasible to develop the optimal system using these alternatives because these alternatives are already available in the market.

**3.3.3.1.2. Determination of Separation measures**

The TOPSIS procedure is based on the concept that the chosen option should be nearest to the HBS and farthest from the HWS. The separation measure of top ranked FPLSC ensures that it is closest to the HBS (best possible FPLSC) and farthest from the HWS (worst possible FPLSC). If $S_i^*$ and $S_i^-$ are separation measures from HBS and HWS, respectively. Then, the separation of each alternative from the HBS is given by

$$S_i^* = [\sum_{j=1}^{n}(v_{ij} - v_j^*)^2]^{1/2} \quad (I = 1, 2, 3\ldots, m) \qquad (13)$$

And separation measure from HWS is given by

$$S_i^- = [\sum_{j=1}^{n}(v_{ij} - v_j^-)^2]^{1/2} \quad (I = 1, 2, 3\ldots, m) \qquad (14)$$

3.3.3.1.3. Determination of suitability index

The suitability index, 'C*' is a measure of the suitability of the FPLSC for the chosen application on the basis of attributes considered. It is defined as the relative closeness to the HBS, and is expressed as

$$C^* = S_i^- / (S_i^* + S_i^-), \qquad I = 1, 2,\ldots., m \qquad (15)$$

An FPLSC with largest C* is preferable.

3.3.3.1.4. Establishing an order of preference

The FPLSC with highest value of C* will be given highest rank, and so on. In this way the preference order for the available alternative FPLSC is obtained by arranging them in decreasing order of their corresponding C* values.

**3.3.3.2 Line Graph**

TOPSIS approach is pure mathematical. Mathematical expressions are developed for the ranking of the systems. Graphical techniques like line graph and spider graph are useful to analyze the information from the weighted normalize matrix. A Line graph as shown in fig 3.2 between the attributes ($A_1$, $A_2$, -, -, -, -, $A_{n-1}$, $A_n$) and the corresponding weighted normalized values.

$$\text{Area} = (d_{I,1} + 2(d_{I,2} + \_\_ + d_{I,j}\_\_\_ + d_{I,n-1}) + d_{I,n})/2 \qquad (16)$$

$d_{i,j}$– represent the weighted normalized value of $j^{th}$ attribute in $i^{th}$ system

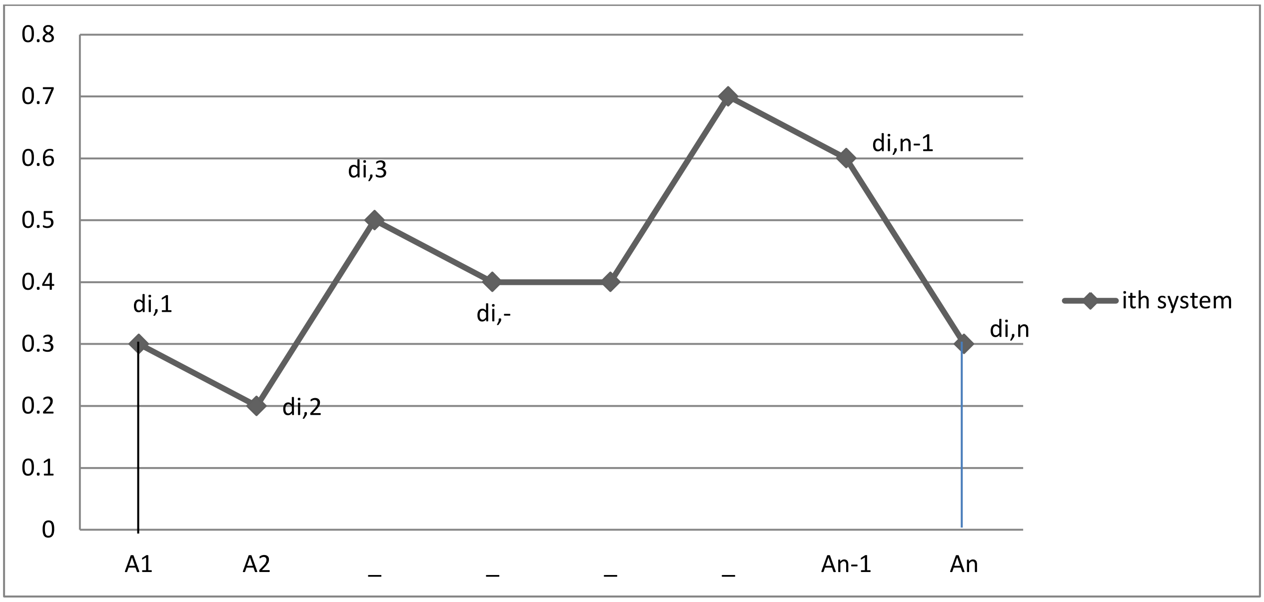


Fig3.2 Line Graph between attributes and normalized values for $i^{th}$ system

Every system has its distinct line graph. So for all selected systems different line graph are developed which are used for the comparison. Area under the graph is the criteria used to compare the systems. System occupy largest area is the most favorable system. Value of attributes like accuracy that is need to minimum, reciprocal the corresponding values of weighted normalized matrix of those attributes and then plot on the graph. This brings the consistency because all attributes are maximized to reach the best possible solution.

### 3.3.3.3 Spider Graph

Similar to the line graph, spider graph is also used to analyze the information of weighted normalize matrix. Spider graph as shown in fig 3.3 is drawn for the $i^{th}$ system between the attributes and the weighted normalized values. Similar to line graph, spider graph is also useful for the comparison of the systems. Area cover by the $i^{th}$ system is:

$$\text{Area} = (\sin\theta/2)\ \sum_{j=1}^{n} d_{I,j} \times d_{i.j+1}\ ; \qquad \text{Where } d_{i,\,n+1} = d_{i,1} \text{ and } \theta = 360/n \qquad (17)$$

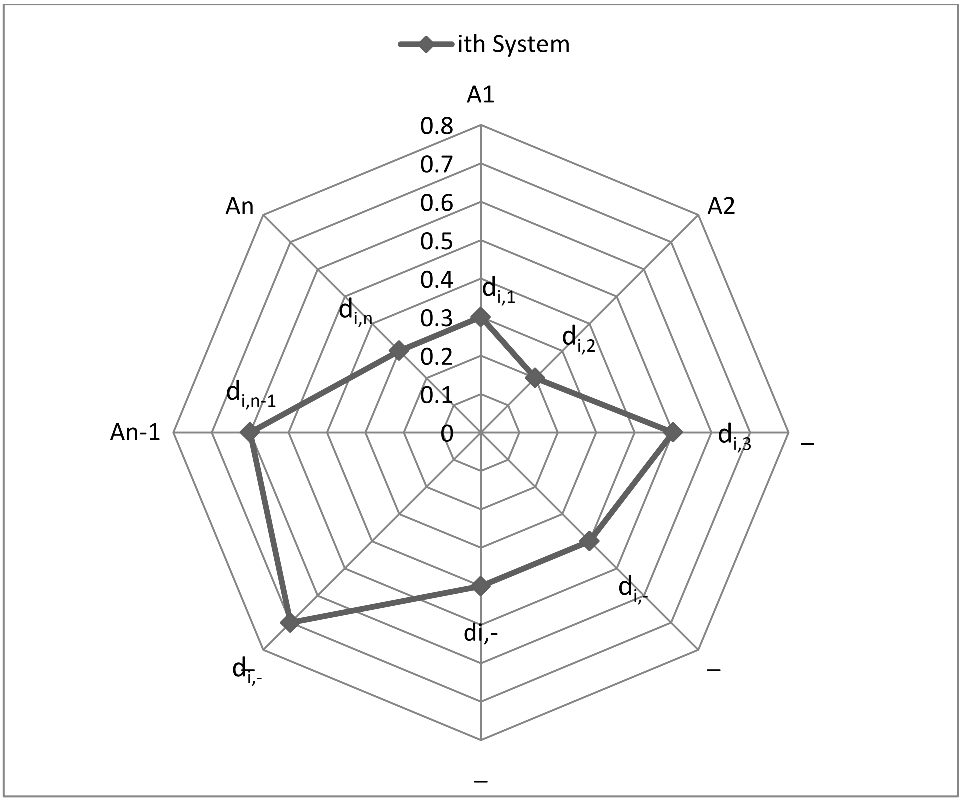


Fig 3.3 Spider Graph for the i$^{th}$ system

### 3.3.4 Illustrative Example

FPLSC is needed for domestic water heating in the winter season at the location Patiala. The monthly average ambient temperature and solar irradiance are shown in table 3.5. From the table 3.5, it is clear that the hot water requirements are mainly in the months from October to March. Output temperature of water required is above 45$^0$C. The temperature variation at Patiala through the year is very high. FPLSC has also to face high temperature in summer season under no working condition, so the stagnation temperature of the collector should be higher than 150$^0$C.

Table 3.5
Average data for different months for the location Patiala

| Month | Ambient temperature (°C) | Solar irraiance (kWH/m²/day) |
|---|---|---|
| January | 11.8 | 3.57 |
| February | 15.0 | 4.61 |
| March | 19.8 | 5.71 |
| April | 26.8 | 6.81 |
| May | 30.7 | 7.42 |
| June | 31.8 | 7.12 |
| July | 30.2 | 5.89 |
| August | 29.2 | 5.46 |
| September | 27.8 | 5.62 |
| October | 23.7 | 5.29 |
| November | 18.1 | 4.32 |
| December | 13.6 | 3.45 |

Step-1: Elimination search

Information about the number of available collectors in the market is collected as shown in table 3.6.

Table 3.6
Flat plate solar collector's specifications

| FPLSC | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Company | Bosch solar thermal | Wagner & Co | Schuco USA LLLP | StiebelEltron | Oventrop Corporation | Thermo Dynamics Ltd. | SUNDA | ACR Solar International |
| Model / Attribute | FKT-1s | EURO C20 AR | SchücoSolAl Silver | Sol 25 | 540 03 07 | G32-P | PG2.0-F/G | Skyline 20-01 |
| M1 | Copper | Copper | Copper | Copper | Copper | Aluminum | Aluminum | Copper |
| M2 | Highly selective PVD | Highly selective vaccum coating | Sunselect | Sputtered titanium nitride | Selective Coating | Moderately Selective Black Paint | Anodizing ( black) | Selective Coating |
| A8 | 95%±2% | 95% | 95% | 95% | 95%±1% | 95% | 90% | 0 |
| A10 | 5%±2% | 5% | 5% | 5% | 10.5%±1.5% | 25% | 20% | 0 |
| M3 | Copper | Copper | Copper | Copper | Copper | Copper | Copper | Copper |
| M4 | Glass | Glass | Glass | Tempered Glass | Tempered Glass | Tempered Glass | Textured tempered glass | Lexan Polycarbonate |
| A22 | 91.50% | 96% | 91% | 92% | 0% | 89.50% | 0% | 0% |
| M6 | Mineral wool | Mineral wool | Mineral wool | Mineral wool | Polyisocyanurate | Fiberglass | Glass insulation | Polyisocyanurate |
| M7 | Fiber glass | Aluminium | Aluminium silver | Anodized Aluminum | Anodized Aluminum | Aluminum | Aluminum Alloy | Aluminum |
| M8 | Copper | 0 | 0 | 0 | Copper | 0 | 0 | 0 |
| M10 ($m^2$) | 2.41 | 2.36 | 2.51 | 2.6 | 1.76 | 2.78 | 1.83 | 1.72 |
| M17 (mm) | 3.2 | 4 | 4 | 0 | 3.2 | 3.2 | 4 | 0 |
| M18 (mm) | 55 | 60 | 40 | 0 | 19 | 25 | 30 | 0 |
| M21 | Ultrasonic welding | 0 | 0 | 0 | High frequency forge welded | Integral | 0 | 0 |
| M39 ($^0$C) | 188 | 232 | 210 | 210 | 0 | 170 | 0 | 0 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| M40 (⁰C) | 120 | 0 | 120 | | 0 | 200 | 130 | 0 |
| M41 (bar) | 10 | 10 | 10 | 6 | 0 | 17.24 | 8 | 11.03 |
| M42 (L/hr) | 50 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M62 (Kg) | 44 | 48 | 55 | 49 | 34.5 | 43.5 | 42 | 17.2 |
| M5 | 0 | sunrac anti reflex coating | 0 | 0 | 0 | 0 | 0 | 0 |
| M53 (bar) | 0 | 0 | 3.2 | 3.5 | 11.4 | 1.35-2.7 | 0 | 0 |
| M48 (L/hr) | 0 | 0 | 0 | 50-300 | 114-410 | 48-90 | 0 | 0 |
| M30 (Years) | 0 | 0 | 0 | 0 | 5 | 10 (Absorber) | 0 | 0 |
| M32 (Years) | 0 | 0 | 0 | 0 | 30 | 0 | 0 | 0 |
| M19 (mm) | 0 | 0 | 0 | 0 | 0 | 20-25 | 0 | 0 |
| M63 (kg/m³) | 0 | 0 | 0 | 0 | 0 | 0 | 32 | 0 |
| M64 (kg/m³) | 0 | 0 | 0 | 0 | 0 | 0 | 64 | 0 |
| M65 (mm) | 55 | 60 | 40 | 0 | 19 | 25 | 25 | 0 |
| M15 | Double meander piping | header and riser | meander | 0 | header and riser | header and riser | header and riser | 0 |
| M66 | 0 | 0 | 0 | 0 | 0 | 0 | Fin & tube | 0 |
| M60 (mm) | 0 | 0 | 0 | 0 | 0 | 0 | 22 | 0 |
| M67 (mm) | 0 | 0 | 0 | 0 | 0 | 0 | 138 | 0 |

| FPLSC | | | | | | |
|---|---|---|---|---|---|---|
| | 9 | 10 | 11 | 12 | 13 | 14 |
| Company | Agua Del Sol | Alternate Energy Technologies | Alternate Energy Technologies | Baymak Group | Beijing Chiner New Energy Technology Co., Ltd. | Big Solar Inc. |
| Model / Attribute | Radco 412C-HP | Alternate Energy AE-32 | Morning Star MSC-32E | Baymak Essential X | Chiner&Isolar PGL2.0-l | Sky Runner SR-20 |
| M1 | Copper | Copper | Copper | Aluminum | Aluminum | Copper |
| M2 | Black Chrome | Selective coating | Moderately Selective Black Paint | Selective coating | Selective coating | Selective coating |

| | | | | | | |
|---|---|---|---|---|---|---|
| A8 | 0 | 0 | 0 | 0 | 0 | 0 |
| A10 | 0 | 0 | 0 | 0 | 0 | 0 |
| M3 | Copper | Copper | Copper | Copper | Copper | Copper |
| M4 | Low Iron Tempered Glass | Low Iron Tempered Glass | Low Iron Tempered Glass | Tempered glass | Tempered glass | Poly |
| A22 | 0% | 0% | 0% | 0% | 0% | 0% |
| M6 | Fiberglass &polyisocyanurate | Polyisocyanurate | Polyisocyanurate | Fiber + no side | Fiber | Foam |
| M7 | Aluminum | Anodized Aluminum | Anodized Aluminum | Aluminum | Aluminum | Aluminum |
| M8 | 0 | 0 | 0 | 0 | 0 | 0 |
| M10 ($m^2$) | 4.21 | 2.78 | 2.74 | 1.88 | 1.82 | 1.76 |
| M17 (mm) | 0 | 0 | 0 | 0 | 0 | 0 |
| M18 (mm) | 0 | 0 | 0 | 0 | 0 | 0 |
| M21 | 0 | 0 | 0 | 0 | 0 | 0 |
| M39 ($^0$C) | 0 | 0 | 0 | 0 | 0 | 0 |
| M40 ($^0$C) | | 0 | 0 | 0 | 0 | 0 |
| M41 (bar) | 11.03 | 11.03 | 11.03 | 15 | 13.45 | 11.03 |
| M42 (L/hr) | 0 | 0 | 0 | | | |
| M62 (Kg) | 70.3 | 51.2 | 57.6 | 41 | 30.5 | 19.2 |
| M5 | 0 | 0 | 0 | 0 | 0 | 0 |
| M53 (bar) | 0 | 0 | 0 | 0 | 0 | 0 |
| M48 (L/hr) | 0 | 0 | 0 | 0 | 0 | 0 |
| M30 (Years) | 0 | 0 | 0 | 0 | 0 | 0 |
| M32 (Years) | 0 | 0 | 0 | 0 | 0 | 0 |
| M19 (mm) | 0 | 0 | 0 | 0 | 0 | 0 |
| M63 ($kg/m^3$) | 0 | 0 | 0 | 0 | 0 | 0 |
| M64 ($kg/m^3$) | 0 | 0 | 0 | 0 | 0 | 0 |
| M65 (mm) | 0 | 0 | 0 | 0 | 0 | 0 |
| M15 | 0 | 0 | 0 | 0 | 0 | 0 |
| M66 | 0 | 0 | 0 | 0 | 0 | 0 |
| M60 (mm) | 0 | 0 | 0 | 0 | 0 | 0 |
| M67 (mm) | 0 | 0 | 0 | 0 | 0 | 0 |

| FPLSC | | | | | | | |
|---|---|---|---|---|---|---|---|
| | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
| Company | Bubbling Springs Solar, | Caleffi Solar | Chromagen | Creative Solar Energy Co., Ltd | DDR Americas Inc. | Dimas SA | Dimplex North America Ltd. |

| | Inc. | | | | | | |
|---|---|---|---|---|---|---|---|
| Model / Attribute | Main Stream MS 29 | SolarFlat NAS10408 A | Chromagen CR-130-SP | Creative Solar CT Black | DDR Americas Inc. SOLARZ UM 18 | Dimas SA Energy + ECO 25 | Dimplex DSCA-2M |
| M1 | Aluminum | Copper | Copper | Copper | Copper | Aluminum | Copper |
| M2 | Moderately Selective Black Paint | Selective | Sputtered Selective | Selective coating | Sputtered aluminium nitride | non-selective coating | Selective coating |
| A8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| A10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M3 | Copper | Copper | Copper | Copper | Copper | Copper | Copper |
| M4 | Low Iron Tempered Glass | Tempered glass | Low Iron Tempered Glass | Tempered glass | Low Iron Tempered Glass | Tempered glass | Tempered glass |
| A22 | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| M6 | Fiberglass | Polyurethane, Fiber glass | Mineral Wool &Poyurethane [Foil-Faced] | Fiberglass | Foil-faced fiberglass + paper faced fiberglass | Fiber | Fiber |
| M7 | Aluminum | Aluminum | Aluminum | Aluminum | Aluminum | Aluminum | Aluminum |
| M8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M10 ($m^2$) | 2.73 | 2.8 | 2.73 | 1.86 | 1.66 | 2.31 | 1.86 |
| M17 (mm) | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M18 (mm) | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M21 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M39 ($^0$C) | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M40 ($^0$C) | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M41 (bar) | 11.03 | 13.5 | 5.51 | 11.03 | 11.03 | 24 | 8.96 |
| M42 (L/hr) | | | | | | | |
| M62 (Kg) | 50.5 | 51.7 | 54 | 39.9 | 35.6 | 41 | 38 |
| M5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M53 (bar) | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M48 (L/hr) | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M30 (Years) | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M32 (Years) | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M19 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| (mm) | | | | | | | |
| M63 (kg/m³) | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M64 (kg/m³) | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M65 (mm) | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M66 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M60 (mm) | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M67 (mm) | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| FPLSC | | | | | | | |
|---|---|---|---|---|---|---|---|
| | 22 | 23 | 24 | 25 | 26 | 27 | 28 |
| Company | EchoFirst Inc. | EnerWorks, Inc. | Energy Conservation Products and Services | Environmental Solar Systems | Evosolar | Ezinc Metal SanayiveTicaret A.S. | F.D.E. Solar Srl |
| Model / Attribute | Cleanline-Thermal CL-T-370 | Residential Collector COL-4x8-TL-SG1-SD10US | Solarway 6000 | Sun Mate SM-14 | Evosolar EVOP | EZINC Superline XXL USB | Collector Harp Shaped Absorber FDE2.1AV |
| M1 | Copper | Aluminum | Fibrous mat spun fiberglass | Aluminum | Aluminum | Copper | Aluminum |
| M2 | Black chrome | Vapor Deposition Selective Coating | None | Selective coating | Sputtered selective | Selective | Selective |
| A8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| A10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M3 | | Copper | | | Copper | Copper | Copper |
| M4 | Tempered glass | Low Iron Tempered Glass | Fiberglass Reinforced Plastic | Low Iron Tempered Glass | Tempered Glass | Tempered Glass | Tempered Glass |
| A22 | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| M6 | None | Mineral Wool+Isocyanurate | Polyisocyanurate | Polyisocyanurate | Rock wool + glass wool | Polyurethane, Fiber glass | Fiber+ no side |
| M7 | Aluminum | Galvanized steel | Sheet metal | Aluminum extrusion | Aluminum | Aluminum | Aluminum |
| M8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M10 (m²) | 31.64 | 2.69 | 2.7 | 1.6 | 2.4 | 2.8 | 1.86 |
| M17 (mm) | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M18 (mm) | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| M21 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M39 ($^{0}C$) | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M40 ($^{0}C$) | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M41 (bar) | 0 | 5.17 | 0 | 0 | 11.06 | 13.5 | 9 |
| M42 (L/hr) | | | | | | | |
| M62 (Kg) | 471.7 | 50.4 | 48.1 | 39 | 50 | 51.7 | 39 |
| M5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M53 (bar) | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M48 (L/hr) | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M30 (Years) | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M32 (Years) | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M19 (mm) | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M63 ($kg/m^3$) | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M64 ($kg/m^3$) | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M65 (mm) | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M66 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M60 (mm) | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M67 (mm) | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| FPLSC | | | | | | |
|---|---|---|---|---|---|---|
| | 29 | 30 | 31 | 32 | 33 | 34 |
| Company | Free Hot Water | GREENoneTECSolarindustrie GmbH | Genersys PLC | Grand Solar Co., Ltd. | Gull Industries | HEWALEX Sp.zo.o. Sp.k. |
| Model / Attribute | Free Hot Water FHW-FC50221 | SK500N FK7250N | ThermosolarGenersys / 1000-10 | Grand Solar GSOL-P20 | Gull 5000 | Hewalex KS2500 TP AC / TLP AC |
| M1 | Copper | Copper | Al | Copper | Copper | Aluminum |
| M2 | Selective coating | Selective coating | Selective coating | Selective coating | mildly selective coating | Selective |
| A8 | 0 | 0 | 0 | 0 | 0 | 0 |
| A10 | 0 | 0 | 0 | 0 | 0 | 0 |

| | | | | | | |
|---|---|---|---|---|---|---|
| M3 | Copper | Copper | Copper | Copper | Copper | Copper |
| M4 | Tempered Glass | Tempered Glass | Tempered Glass | Tempered Glass | Tempered Glass | Tempered Glass |
| A22 | 0% | 0% | 0% | 0% | 0% | 0% |
| M6 | Rockwool | Rock Wool | Fiber | Rock Wool | foam | Fiber |
| M7 | Aluminum | Aluminum | Aluminum | Aluminum | Aluminum | Aluminum |
| M8 | 0 | 0 | 0 | 0 | 0 | 0 |
| M10 ($m^2$) | 1.85 | 2.34 | 1.78 | 1.85 | 2.79 | 2.24 |
| M17 (mm) | 0 | 0 | 0 | 0 | 0 | 0 |
| M18 (mm) | 0 | 0 | 0 | 0 | 0 | 0 |
| M21 | 0 | 0 | 0 | 0 | 0 | 0 |
| M39 ($^0C$) | 0 | 0 | 0 | 0 | 0 | 0 |
| M40 ($^0C$) | 0 | 0 | 0 | 0 | 0 | 0 |
| M41 (bar) | 9 | 11.03 | 8 | 9 | 11.03 | 15 |
| M42 (L/hr) | 0 | 0 | 0 | 0 | 0 | 0 |
| M62 (Kg) | 38 | 49 | 37 | 38 | 60.3 | 44 |
| M5 | 0 | 0 | 0 | 0 | 0 | 0 |
| M53 (bar) | 0 | 0 | 0 | 0 | 0 | 0 |
| M48 (L/hr) | 0 | 0 | 0 | 0 | 0 | 0 |
| M30 (Years) | 0 | 0 | 0 | 0 | 0 | 0 |
| M32 (Years) | 0 | 0 | 0 | 0 | 0 | 0 |
| M19 (mm) | 0 | 0 | 0 | 0 | 0 | 0 |
| M63 ($kg/m^3$) | 0 | 0 | 0 | 0 | 0 | 0 |
| M64 ($kg/m^3$) | 0 | 0 | 0 | 0 | 0 | 0 |
| M65 (mm) | 0 | 0 | 0 | 0 | 0 | 0 |
| M15 | 0 | 0 | 0 | 0 | 0 | 0 |
| M66 | 0 | 0 | 0 | 0 | 0 | 0 |
| M60 (mm) | 0 | 0 | 0 | 0 | 0 | 0 |
| M67 (mm) | 0 | 0 | 0 | 0 | 0 | 0 |

| FPLSC | | | | | | | |
|---|---|---|---|---|---|---|---|
| | 35 | 36 | 37 | 38 | 39 | 40 | 41 |
| Company | Heliodyne, Inc. | Heat Transfer Products | Helioakmi S.A. | Heliodyne, Inc. | Hyperion America, Inc. | Integrated Solar LLC | Juli New Energy Co., Ltd. |
| Model / Attribute | GOBI 408 001 | Solar Spectrum FP-26SC | Megasun ST 2000 | GOBI 410 002 | HYPERION FHY2220 | Architectural Series AS408P | Juli New Energy JLS-FP-WS-2.05 |
| M1 | Aluminum | Copper | Copper | Aluminum | Copper | Copper | Aluminum |
| M2 | Selective coating | Selective coating | Selective | Mildly selective coating | Selective | Non Selective coating | Selective coating |
| A8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| A10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M3 | Copper | Copper | Copper | Copper | Copper | Copper | Copper |
| M4 | Tempered Glass | Low iron Tempered Glass | Tempered Glass | Tempered Glass | Tempered Glass | Tempered Glass | Tempered Glass |
| A22 | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| M6 | foam | Polyisocyanurate | Fiber | Foam | Foam (side)+ Fiber glass (back) | Foam (side)+ Foam, Fiber glass (back) | Fiber (back) |
| M7 | Aluminum | Anodized Aluminum | Aluminum | Aluminum | Aluminum | Aluminum | Aluminum |
| M8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M10 ($m^2$) | 2.78 | 2.2 | 1.8 | 3.47 | 1.86 | 2.8 | 1.79 |
| M17 (mm) | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M18 (mm) | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M21 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M39 ($^0$C) | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M40 ($^0$C) | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M41 (bar) | 11.03 | 11.03 | 12.15 | 11.03 | 13.5 | 11.03 | 11.03 |
| M42 (L/hr) | | | | | | | |
| M62 (Kg) | 46.3 | 40.8 | 42.5 | 43.5 | 42 | 50.1 | 42 |
| M5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M53 (bar) | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M48 (L/hr) | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M30 (Years) | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M32 (Years) | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M19 (mm) | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M63 ($kg/m^3$) | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M64 ($kg/m^3$) | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M65 (mm) | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| M15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M66 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M60 (mm) | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| M67 (mm) | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| FPLSC | | | | | | |
|---|---|---|---|---|---|---|
| | 42 | 43 | 44 | 45 | 46 | 47 |
| Company | KBB Kollektorbau | KIOTO Clear Energy S.A. de C.V. | Kingspan Solar Inc. | Lochinvar Corporation | MC2 Energy Inc. | MGL, LLC |
| Model / Attribute | KBB K420-MS-AL | KIOTO Clear Energy FP 1.20.0 LE sc | Kinspan Solar Flat Plate FP200 | Lochinvar/TiSun SCH090 | ESOLAIR 2.0 3G | AQASOL AQASOL AZ 22 |
| M1 | Aluminum | Aluminum | Copper | Aluminum | Aluminum | Aluminum |
| M2 | Selective coating | Selective | Selective | Selective vapor deposition | Selective coating | Selective |
| A8 | 0 | 0 | 0 | 0 | 0 | 0 |
| A10 | 0 | 0 | 0 | 0 | 0 | 0 |
| M3 | Copper | Aluminum | Copper | Copper | Aluminum | Copper |
| M4 | Tempered Glass | Solar glass | Tempered Glass | Low iron Tempered Glass | Tempered Glass | Solar glass |
| A22 | 0% | 0% | 0% | 0% | 0% | 0% |
| M6 | Fiber | Polyunrethane (side)+ foam (back) | Rockwool | Mineral wool (side) + Rigid foam (back) | Fiber | Polyunrethane (side)+ Rockwool (back) |
| M7 | Aluminum | Aluminum | Stainless steel | Aluminum | Aluminum | Aluminum |
| M8 | 0 | 0 | 0 | 0 | 0 | 0 |
| M10 (m²) | 1.97 | 1.89 | 1.87 | 7.04 | 2.42 | 1.89 |
| M17 (mm) | 0 | 0 | 0 | 0 | 0 | 0 |
| M18 (mm) | 0 | 0 | 0 | 0 | 0 | 0 |
| M21 | 0 | 0 | 0 | 0 | 0 | 0 |
| M39 ($^0$C) | 0 | 0 | 0 | 0 | 0 | 0 |
| M40 ($^0$C) | 0 | 0 | 0 | 0 | 0 | 0 |
| M41 (bar) | 15 | 15 | 11.03 | 11.03 | | 15 |
| M42 (L/hr) | | | | | | |
| M62 (Kg) | 34.5 | 27 | 34 | 186 | 57.2 | 28 |
| M5 | 0 | 0 | 0 | 0 | 0 | 0 |
| M53 (bar) | 0 | 0 | 0 | 0 | 0 | 0 |
| M48 (L/hr) | 0 | 0 | 0 | 0 | 0 | 0 |
| M30 (Years) | 0 | 0 | 0 | 0 | 0 | 0 |
| M32 (Years) | 0 | 0 | 0 | 0 | 0 | 0 |

| | | | | | | |
|---|---|---|---|---|---|---|
| M19 (mm) | 0 | 0 | 0 | 0 | 0 | 0 |
| M63 (kg/m³) | 0 | 0 | 0 | 0 | 0 | 0 |
| M64 (kg/m³) | 0 | 0 | 0 | 0 | 0 | 0 |
| M65 (mm) | 0 | 0 | 0 | 0 | 0 | 0 |
| M15 | 0 | 0 | 0 | 0 | 0 | 0 |
| M66 | 0 | 0 | 0 | 0 | 0 | 0 |
| M60 (mm) | 0 | 0 | 0 | 0 | 0 | 0 |
| M67 (mm) | 0 | 0 | 0 | 0 | 0 | 0 |

| FPLSC | | | | | |
|---|---|---|---|---|---|
| | 48 | 49 | 50 | 51 | 52 |
| Company | Magen Eco-Energy | Magen Eco-Energy | Millionsun Energy Co., Ltd. | Mr. Sun Solar | NY Thermal Inc. (NTI) |
| Model / Attribute | eco FLARE 3M | Baxi S-SPC 18 | Milsun M-SBC/2.0-Black | Sol-Reliant AE-40 | NTI Sol-R-Therm SRT-215 |
| M1 | Poly | Copper | Copper | Copper | Aluminum |
| M2 | Poly | Selective coating | Selective coating | Selective coating | Selective coating |
| A8 | 0 | 0 | 0 | 0 | 0 |
| A10 | 0 | 0 | 0 | 0 | 0 |
| M3 | Poly | Copper | Copper | Copper | Copper |
| M4 | Poly | Low iron Tempered Glass | Tempered Glass | Low iron Tempered Glass | Tempered Glass |
| A22 | 0% | 0% | 0% | 0% | 0% |
| M6 | Foam (back) | Glasswool | Fiberglass | Polyisocyanurate | Foam & fiber (back) |
| M7 | Aluminum, Poly | Aluminum Extrusion | Aluminum | Anodized Aluminum | Aluminum |
| M8 | 0 | 0 | 0 | 0 | 0 |
| M10 (m²) | 1.86 | 1.7 | 1.86 | 3.48 | 1.92 |
| M17 (mm) | 0 | 0 | 0 | 0 | 0 |
| M18 (mm) | 0 | 0 | 0 | 0 | 0 |
| M21 | 0 | 0 | 0 | 0 | 0 |
| M39 ($^0$C) | 0 | 0 | 0 | 0 | 0 |
| M40 ($^0$C) | 0 | 0 | 0 | 0 | 0 |
| M41 (bar) | 7 | 11.03 | 11.03 | 11.03 | 11.03 |
| M42 (L/hr) | 0 | 0 | 0 | 0 | 0 |
| M62 (Kg) | 11.7 | 32.8 | 39.9 | 69.4 | 31.9 |
| M5 | 0 | 0 | 0 | 0 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| M53 (bar) | 0 | 0 | 0 | 0 | 0 |
| M48 (L/hr) | 0 | 0 | 0 | 0 | 0 |
| M30 (Years) | 0 | 0 | 0 | 0 | 0 |
| M32 (Years) | 0 | 0 | 0 | 0 | 0 |
| M19 (mm) | 0 | 0 | 0 | 0 | 0 |
| M63 (kg/m³) | 0 | 0 | 0 | 0 | 0 |
| M64 (kg/m³) | 0 | 0 | 0 | 0 | 0 |
| M65 (mm) | 0 | 0 | 0 | 0 | 0 |
| M15 | 0 | 0 | 0 | 0 | 0 |
| M66 | 0 | 0 | 0 | 0 | 0 |
| M60 (mm) | 0 | 0 | 0 | 0 | 0 |
| M67 (mm) | 0 | 0 | 0 | 0 | 0 |

The minimum requirement for to fulfill the objective are absorber and tubes are made of metal, bonding material used is of high thermal conductivity and tolerate high temperature conditions. Glazing must be required with high transmittance at least 85%. Collectors are selected from the available list those are able to fulfill these requirements are shown in table 3.7.

Table 3.7

Manufacturer list of selected systems

| System | Model | Company |
|---|---|---|
| 1 | FKT-1s Portrait | Bosch solar thermal |
| 2 | EURO C20 AR | Wagner & Co |
| 3 | SOL 25 | Stiebel Eltron |
| 4 | G 32-P | Thermo Dynamics, ltd. |

Attributes used for the comparison of these collectors are shown in table 3.8.

Table 3.8

Attributes description for selected systems

| System | Transmittance | Stagnation Temperature ($^0$C) | Output (MJ/day/m$^2$) | Maximum Pressure (bar) |
|---|---|---|---|---|
| 1 | 91.5 | 188 | 13.1 | 10 |
| 2 | 96 | 232 | 14.5 | 10 |
| 3 | 92 | 210 | 12.3 | 11 |
| 4 | 89.5 | 170 | 10.4 | 16 |

Step-2: Coding

All the attributes are quantifiable so coding is same as their values.

Step-3: Development of Decision Matrix

Decision matrix is developed from the data available in table 3.8.

$$D = \begin{bmatrix} 91.5 & 188 & 13.1 & 10 \\ 96 & 232 & 14.5 & 10 \\ 92 & 210 & 12.3 & 11 \\ 89.5 & 170 & 10.4 & 16 \end{bmatrix} \quad (18)$$

Step-4: Formation of Normalized matrix

$$N = \begin{bmatrix} .50 & .47 & .51 & .42 \\ .52 & .58 & .57 & .42 \\ .50 & .52 & .48 & .46 \\ .48 & .42 & .43 & .67 \end{bmatrix} \quad (19)$$

Step-5: Define Relative importance matrix

$$R = \begin{bmatrix} 1 & .67 & .5 & .67 \\ 1.5 & 1 & .67 & 1 \\ 2 & 1.5 & 1 & 1.5 \\ 1.5 & 1 & .67 & 1 \end{bmatrix} \quad (20)$$

Step-6: Calculate the Eigen value and the corresponding Eigen vector (Weight vector)

$$\det(R - \lambda I) = 0$$

$$\lambda_{max} = 4 \quad (21)$$

$$(R - \lambda_{max} I)W = 0$$

$$W = \begin{bmatrix} .165 \\ ..242 \\ .351 \\ .241 \end{bmatrix} \quad (22)$$

Step-7: Formation of weight normalization matrix as discussed in section 3.3.2.5.

$$V = \begin{bmatrix} .082 & .113 & .18 & .10 \\ .086 & .139 & .20 & .10 \\ .082 & .126 & .17 & .11 \\ .080 & .102 & .15 & .16 \end{bmatrix} \quad (23)$$

Step-8: find out the HBS and HWS as discussed in section 3.3.3.1.1.

HBS = $A^* = [.086 \quad .139 \quad .20 \quad .16]$
HWS = $A^- = [.080 \quad .102 \quad .15 \quad .10]$ (24)

Step-9: Find out the separation measures as discussed in 3.3.3.1.2.
$S_1^* = .069$, $S_2^* = .060$, $S_3^* = .060$, $S_4^* = .062$
$S_1^- = .032$, $S_2^- = .062$, $S_3^- = .032$, $S_4^- = .060$ (25)

Step-10: Determination of suitability index as discussed in section 3.3.3.1.3.
$C_1^* = .316$, $C_2^* = .506$, $C_3^* = .336$, $C_4^* = .494$ (26)

Ranking of the selected systems is shown in table 3.9 on the basis of C*. System 2 is at the 1st place and system 1 is at the 4th place.

Table 3.9
Ranking of System on the basis of C*

| System | C* | Ranking |
|---|---|---|
| 1 | 0.316 | 4th |
| 2 | 0.506 | 1st |
| 3 | 0.346 | 3rd |
| 4 | 0.494 | 2nd |

Graphical Technique:

Line Graph:

Line graph is drawn for the weighted normalized matrix between the weighted normalized values and the attributes for different systems as shown in fig3.4. Each system is represented by the different color line. This graph can be used for the visual comparison of the systems. As shown in fig 3.4, system 2 is best for the three attributes.

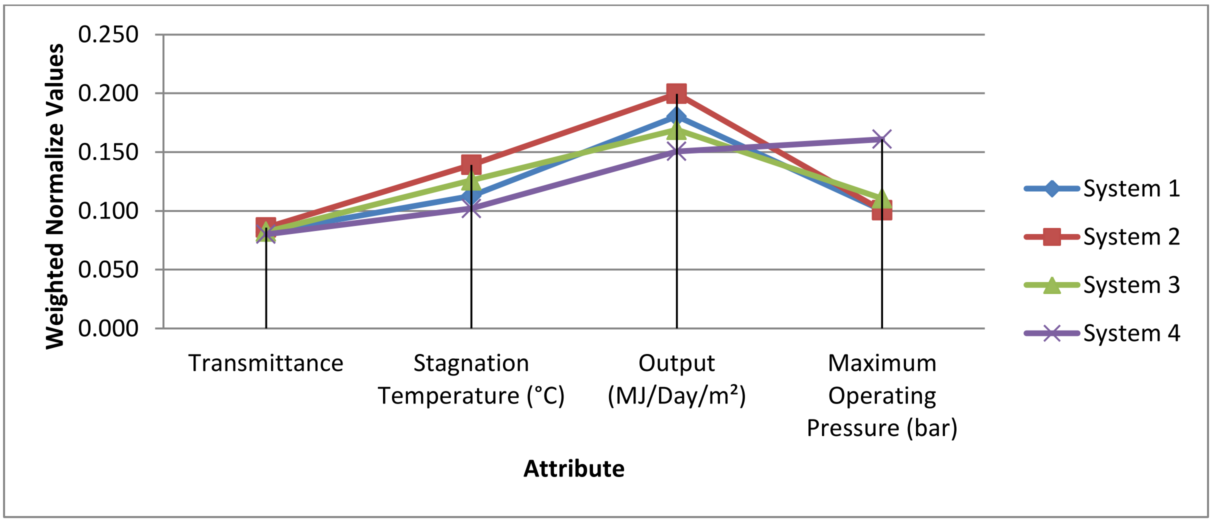


Fig 3.4 Line graph for different systems

The area under the curve for each system is calculated to compare the systems as shown in table3.10.System 2 is at the 1st rank and system 4 is at the 4th rank according to line graph technique.

Table 3.10
Ranking based on line graph

| System | Area From Line Graph | Ranking |
|---|---|---|
| 1 | 0.384 | 3rd |
| 2 | 0.432 | 1st |
| 3 | 0.391 | 2nd |
| 4 | 0.373 | 4th |

Spider graph:

Spider graph is drawn from the normalize matrix data as shown in fig 3.5. Edges represent the attributes and different color line represents different system. Similar to line graph, spider graph can also be used for visual inspection.

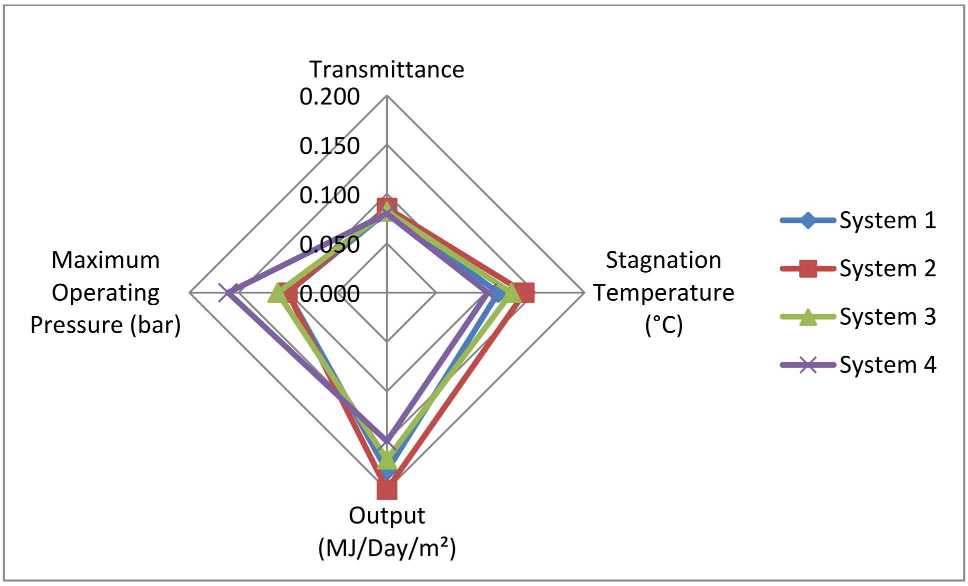


Fig.3.5 Spider Graph for different systems

Ranking of the systems using area under the spider graph criteria is shown in table 3.11From table 3.11, it is found that system 2 at the 1st place and system 1 at the 4th place.

Table 3.11
Ranking based on Spider graph

| System | Area from Spider graph | Ranking |
|---|---|---|
| 1 | 0.0280 | 4th |
| 2 | 0.0342 | 1st |
| 3 | 0.0297 | 3rd |

| | | |
|---|---|---|
| 4 | 0.0303 | 2nd |

**3.3.4.1 Comparison of the three techniques**

Ranking of the systems by different techniques is shown in table 3.12. The results of MADM and spider graph are same. But the results of line graph are much different from these techniques.

Table 3.12

Ranking from different techniques

| System | C* | Ranking | Area From Line Graph | | Area from Spider graph | |
|---|---|---|---|---|---|---|
| 1 | 0.316 | 4th | 0.384 | 3rd | 0.0280 | 4th |
| 2 | 0.506 | 1st | 0.432 | 1st | 0.0342 | 1st |
| 3 | 0.346 | 3rd | 0.391 | 2nd | 0.0297 | 3rd |
| 4 | 0.494 | 2nd | 0.373 | 4th | 0.0303 | 2nd |

Systems C* values and area under the graph values are represented by the percentage of the best value scored as shown in table 3.13 to see the closeness of the results with the best one. From the table 3.13, it is clear that beside MADM and spider graph rankings are same but the closeness of the systems with the best one is much similar between line graph and spider graph.

Table 3.13

System values represented by percentage of best one

| System | C* | Ranking | Area From Line Graph | | Area from Spider graph | |
|---|---|---|---|---|---|---|
| 1 | 62.43 | 4th | 88.97 | 3rd | 81.75 | 4th |
| 2 | 100.00 | 1st | 100.00 | 1st | 100.00 | 1st |
| 3 | 68.33 | 3rd | 90.60 | 2nd | 86.87 | 3rd |
| 4 | 97.67 | 2nd | 86.36 | 4th | 88.60 | 2nd |

**3.3.4.2 Sensitivity analysis**

There are four attributes considered for the evaluation and ranking of the systems. Every attribute has different effect on the value of suitability index. Sensitivity analysis is carried out to see the effect of each attribute on the value of suitability index. Attribute values are changed in the worst selected system that is system 1. Values are increased up to the best hypothetical case values because systems with above those values are not available till yet.

**3.3.4.2.1 Transmittance effect on the ranking of the systems**

Transmittance value is increased of the system 1 and the corresponding values of C* is calculated as sown in table 3.14. The maximum reachable transmittance is 96 that is of best hypothetical case. C* value increases with the increase in transmittance value.

Table 3.14
Transmittance effect on C*

| Transmittance | Normalize value | C* |
|---|---|---|
| 91.5 | 0.495 | 0.316 |
| 92 | 0.497 | 0.316 |
| 93 | 0.501 | 0.317 |
| 94 | 0.505 | 0.318 |
| 95 | 0.509 | 0.318 |
| 96 | 0.513 | 0.319 |

The variation of C* with transmittance is shown in fig 3.6. Assuming linear increase of the C* with transmittance, best fit line is drawn. Slope of the line gives the rate of increase of C* with increase in transmittance.

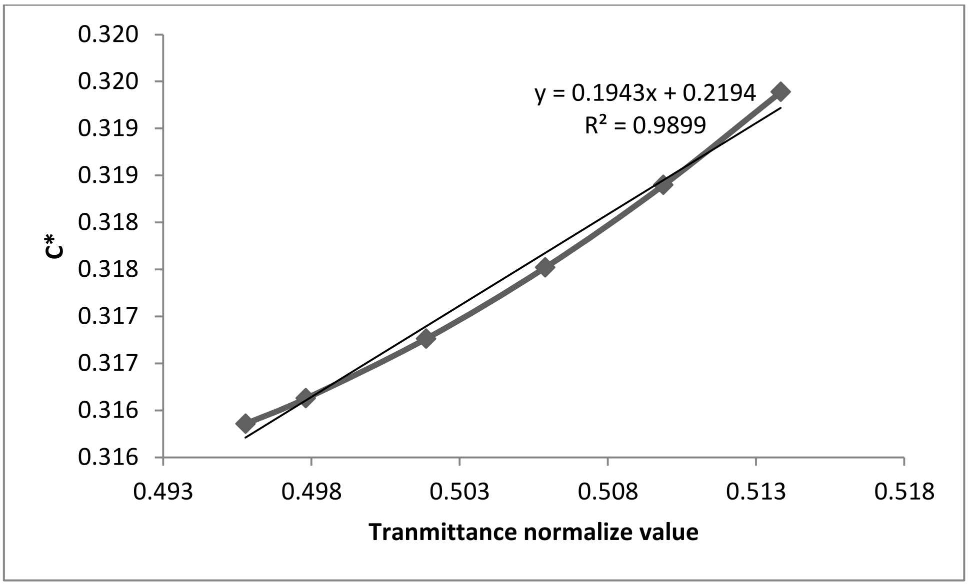


Fig 3.6 Transmittance effect on C*

Taking transmittance of the system 1 as the best one keeping the other attribute values same, C* values and ranking of the systems shown in table 3.15. It is clear that C*value of system 1 increases but it does not affect the system ranking.

Table 3.15
Ranking when system 1 has best transmittance value using C*

| System | C* | Ranking |
|---|---|---|
| 1 | 0.319 | 4th |
| 2 | 0.506 | 1st |
| 3 | 0.346 | 3rd |
| 4 | 0.494 | 2nd |

Table 3.16
Ranking when system 1 has best transmittance value using line graph

| System | Area From Line Graph | Ranking |
|---|---|---|
| 1 | 0.386 | 3rd |
| 2 | 0.432 | 1st |
| 3 | 0.391 | 2nd |
| 4 | 0.373 | 4th |

Similar to the TOPSIS ranking, there is no change in the ranking of the systems with increase in transmittance of the system 1 as shown in table 3.16 using line graph.

Table 3.17
Ranking when system 1 has best transmittance value using spider graph

| System | Area From spider Graph | Ranking |
|---|---|---|
| 1 | 0.0283 | 4th |
| 2 | 0.0341 | 1st |
| 3 | 0.0296 | 3rd |
| 4 | 0.0302 | 2nd |

Similar to the TOPSIS ranking, there is no change in the ranking of the systems with increase in transmittance of the system 1 as shown in table 3.17 using spider graph.

**3.3.4.2.2 Stagnation temperature effect on the ranking of the systems**

Stagnation temperature value is increased of the system 1 and the corresponding values of C* is calculated as sown in table 3.18. The maximum reachable stagnation temperature is 230 that is of best hypothetical case. C* value increases with the increase in stagnation temperature value.

Table 3.18
Stagnation temperature effect on C*

| Stagnation Temperature ($^{0}$C) | Normalize value | C* |
|---|---|---|
| 188 | 0.467 | 0.316 |
| 190 | 0.471 | 0.320 |
| 195 | 0.480 | 0.332 |
| 200 | 0.489 | 0.344 |
| 205 | 0.498 | 0.357 |
| 210 | 0.507 | 0.369 |
| 215 | 0.516 | 0.382 |
| 220 | 0.525 | 0.394 |
| 225 | 0.534 | 0.406 |
| 230 | 0.542 | 0.417 |

The variation of C* with stagnation temperature is shown in fig 3.7. Assuming linear increase of the C* with stagnation temperature, best fit line is drawn. Slope of the line gives the rate of increase of C* with increase in stagnation temperature.

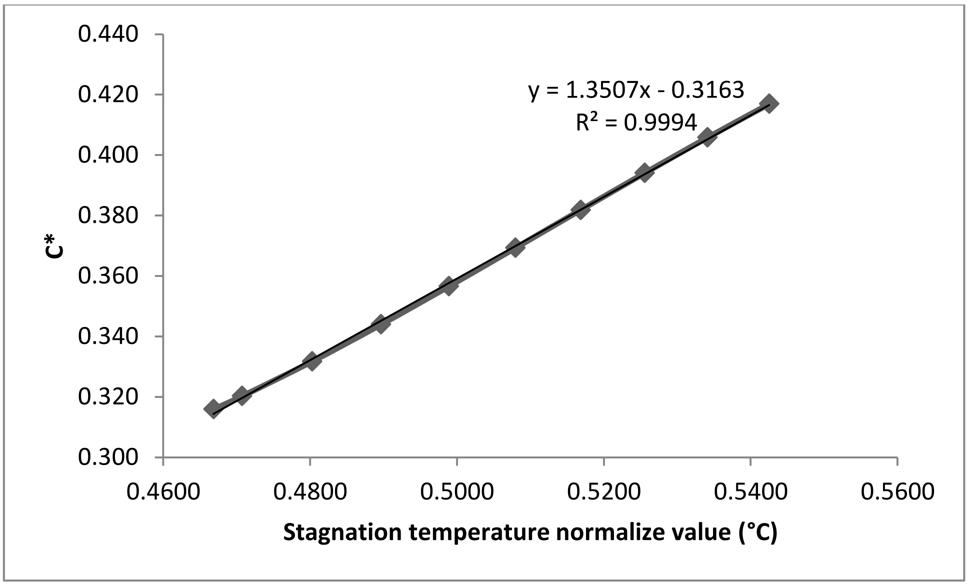


Fig 3.7 Stagnation temperature effect on C*

Taking stagnation temperature of the system 1 as the best one keeping the other attribute values same, C* values and ranking of the systems shown in table 3.19. It is clear that C*value of system 1 increases and the system 1 come at the 3rd position.

Table 3.19

Ranking when system 1 has best stagnation temperature value using C*

| System | C* | Ranking |
|---|---|---|
| 1 | 0.417 | 3rd |
| 2 | 0.501 | 1st |
| 3 | 0.340 | 4th |
| 4 | 0.499 | 2nd |

Table 3.20

Ranking when system 1 has best stagnation temperature value using line graph

| System | Area From Line Graph | Ranking |
|---|---|---|
| 1 | 0.403 | 2nd |
| 2 | 0.425 | 1st |
| 3 | 0.385 | 3rd |
| 4 | 0.368 | 4ht |

There is improvement in the ranking of the system 1 using the best stagnation temperature value as shown in table 3.20 on the basis of line graph. System 1 reaches to 2nd place from 3rd place according to line graph technique.

Table 3.21
Ranking when system 1 has best stagnation temperature value using spider graph

| System | Area from spider graph | Ranking |
|---|---|---|
| 1 | 0.0304 | 2nd |
| 2 | 0.0332 | 1st |
| 3 | 0.0289 | 4th |
| 4 | 0.0297 | 3rd |

There is improvement in the ranking of the system 1 using the best stagnation temperature value as shown in table 3.21 on the basis of spider graph. System 1 reaches to $2^{nd}$ place from $4^{th}$ place according to spider graph technique.

### 3.3.4.2.3 Output effect on the ranking of the systems

Output value is increased of the system 1 and the corresponding values of C* is calculated as sown in table 3.22. The maximum reachable output is 14.49 that is of best hypothetical case. C* value increases with the increase in output value.

Table 3.22
Output effect on C*

| Output ($MJ/m^2day$) | Normalize value | C* |
|---|---|---|
| 13.0973 | 0.51242 | 0.316 |
| 13.5 | 0.52455 | 0.353 |
| 14 | 0.53841 | 0.393 |
| 14.5 | 0.55186 | 0.426 |

The variation of C* with output is shown in fig 3.8. Assuming linear increase of the C* with output, best fit line is drawn. Slope of the line gives the rate of increase of C* with increase in output.

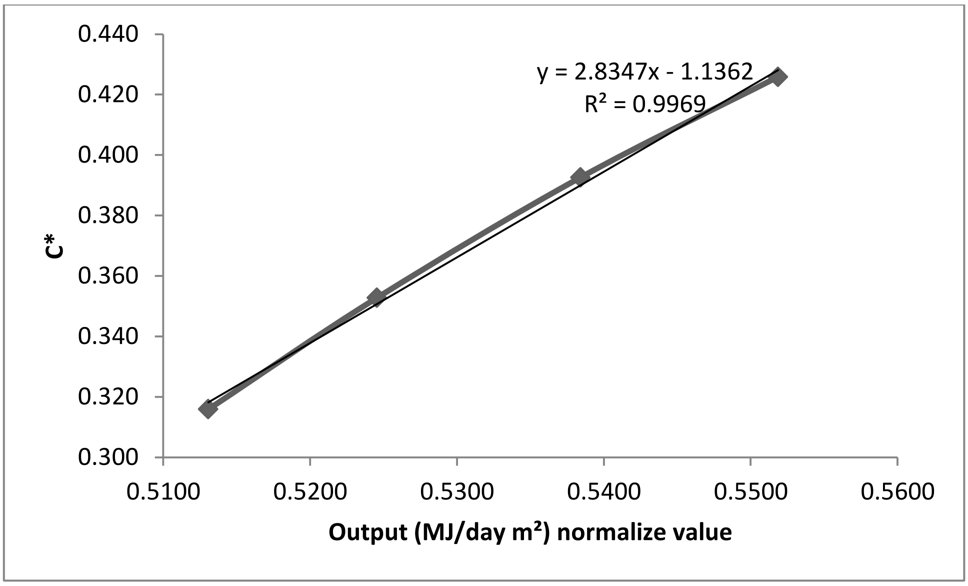


Fig 3.8 Output effect on C*

Taking output of the system 1 as the best one keeping the other attribute values same, C* values and ranking of the systems shown in table 3.23. It is clear that C*value of system 1 increases and the system 1 come at the 3rd position.

Table 3.23
Ranking when system 1 has best output value using C*

| System | C* | Ranking |
|---|---|---|
| 1 | 0.426 | 3rd |
| 2 | 0.50 | 1st |
| 3 | 0.34 | 4th |
| 4 | 0.50 | 2nd |

Table 3.24
Ranking when system 1 has best output value using line graph

| System | Area From Line Graph | Ranking |
|---|---|---|
| 1 | 0.398 | 2nd |
| 2 | 0.426 | 1st |
| 3 | 0.387 | 3rd |
| 4 | 0.369 | 4ht |

There is improvement in the ranking of the system 1 using the best output value as shown in table 3.24 on the basis of line graph. System 1 reaches to 2nd place from 3rd place according to line graph technique.

Table 3.25
Ranking when system 1 has best output value using spider graph

| System | Area from spider graph | Ranking |
|---|---|---|
| 1 | 0.0294 | 3rd |

| | | |
|---|---|---|
| 2 | 0.0336 | 1st |
| 3 | 0.0292 | 4th |
| 4 | 0.0298 | 2nd |

System 1 reaches to the 3rd place from the 4th place using the best output value as shown in table 3.25 on the basis of spider graph.

### 3.3.4.2.4 Pressure effect on the ranking of the systems

Pressure value is increased of the system 1 and the corresponding values of C* is calculated as sown in table 3.26. The maximum reachable Pressure is 16 bar that is of best hypothetical case. C* value increases with the increase in Pressure value.

Table 3.26
Pressure effect on C*

| Pressure (bar) | Normalize value | C* |
|---|---|---|
| 10 | 0.41631 | 0.316 |
| 11 | 0.44982 | 0.359 |
| 12 | 0.48154 | 0.422 |
| 13 | 0.51148 | 0.495 |
| 14 | 0.53966 | 0.564 |
| 15 | 0.56614 | 0.619 |
| 16 | 0.59097 | 0.654 |

The variation of C* with Pressure is shown in fig 3.9. Assuming linear increase of the C* with Pressure, best fit line is drawn. Slope of the line gives the rate of increase of C* with increase in Pressure.

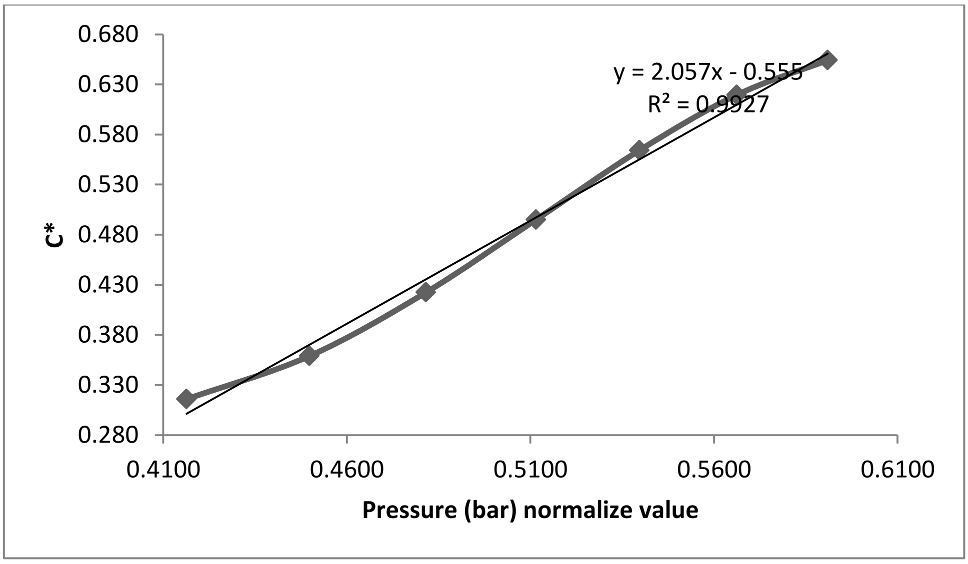


Fig 3.9 Maximum pressure effect on C*

Taking Pressure of the system 1 as the best one keeping the other attribute values same, C* values and ranking of the systems shown in table 3.27. It is clear that C*value of system 1 increases and the system 1 come at the 1$^{st}$position.

Table 3.27
Ranking when system 1 has best pressure value

| System | C* | Ranking |
|---|---|---|
| 1 | 0.654 | 1st |
| 2 | 0.54 | 2nd |
| 3 | 0.36 | 4th |
| 4 | 0.46 | 3rd |

Table 3.28
Ranking when system 1 has best pressure value using line graph

| System | Area From Line Graph | Ranking |
|---|---|---|
| 1 | 0.406 | 2nd |
| 2 | 0.426 | 1st |
| 3 | 0.385 | 3rd |
| 4 | 0.364 | 4ht |

There is improvement in the ranking of the system 1 using the best pressure value as shown in table 3.28 on the basis of line graph. System 1 reaches to 2$^{nd}$ place from 3$^{rd}$ place according to line graph technique.

Table 3.29
Ranking when system 1 has best pressure value using spider graph

| System | Area from spider graph | Ranking |
|---|---|---|
| 1 | 0.0335 | 1st |
| 2 | 0.0326 | 2nd |
| 3 | 0.0282 | 4th |
| 4 | 0.0282 | 3rd |

There is improvement in the ranking of the system 1 using the best pressure value as shown in table 3.29 on the basis of spider graph. System 1 reaches to 1$^{st}$place from 4$^{th}$place according to spider graph technique.

**3.3.4.2.5 Comparison of different attributes effect on the ranking of FPLSCs**

Effect of different attributes on C* is shown in fig 3.10, from the figure it is clear that output attribute is more effective than the other attributes. Varying pressure attribute to best hypothetical value, system 1 reaches to the 1st rank. Stagnation temperature and transmittance are very less effective than the other attributes.

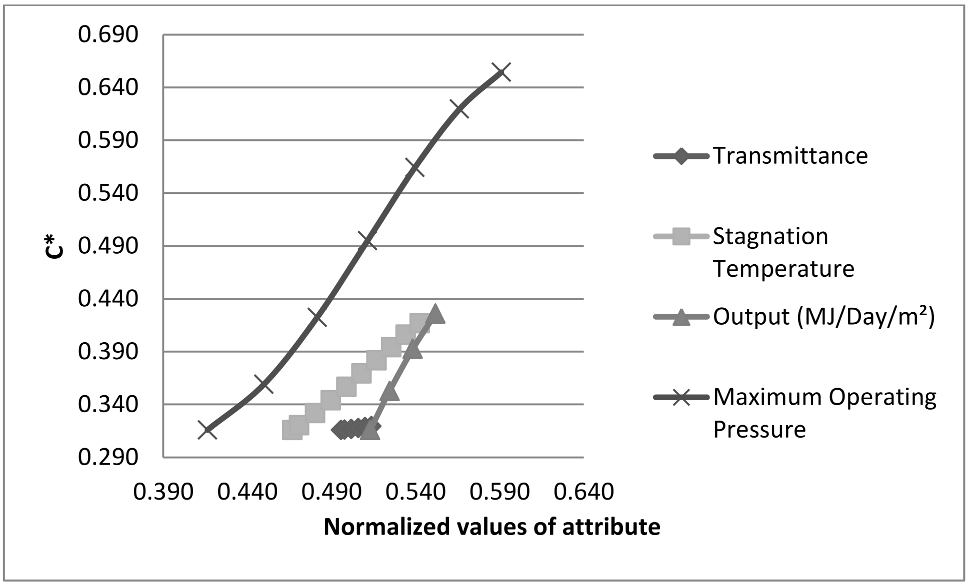


Fig 3.10 Attribute effect on C*

Effect of different attributes on the area under the line is shown in fig 3.11. From the figure it is clear that maximum pressure attribute takes the area of graph maximum. But as per the rate of increase of the area with respect to attribute, stagnation temperature and output are more effective.

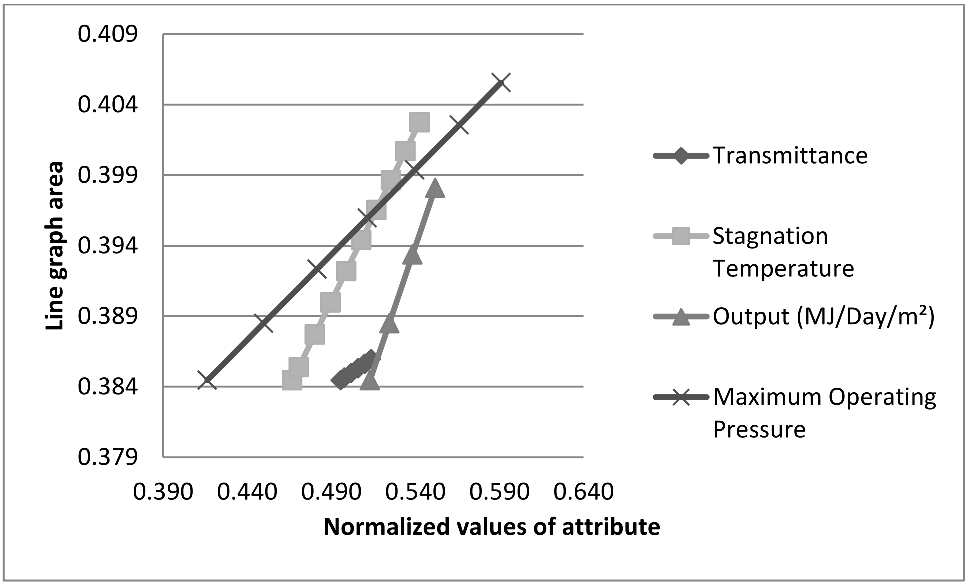


Fig 3.11 Attribute effect on area under the curve of line graph

Effect of different attributes on the area of spider graph is shown in fig 3.12. From the figure it is clear that pressure attribute takes the area of spider graph highest. So effect the optimal selection. Rate of increase of the spider area with any attribute is nearly same as shown in fig 3.12.

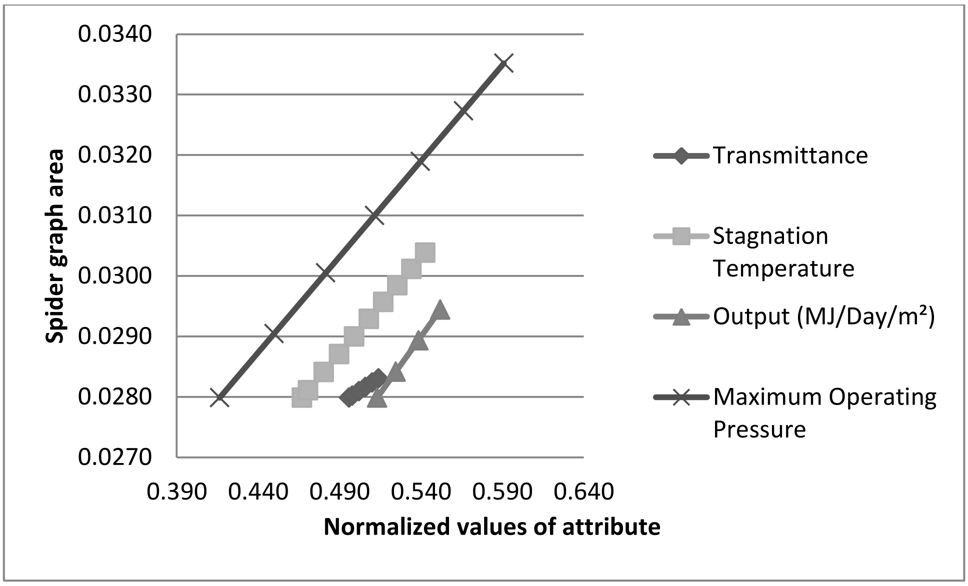


Fig 3.12 Attributes effect on the spider area

From the Figures 3.10, 3.11 and 3.12 it is clear that all the three techniques give different results of sensitivity analysis. Also the results for the optimal selection of the system are different of the approaches. However the results of spider and TOPSIS are same but the relative closeness of the selected systems with the best one is similar of line and spider graph. So it is not true that all the time the results of TOPSIS and spider graph are same. From the above it is clear that all the three techniques are not consistent with each other. But TOPSIS is the standard procedure in MADM for the selection of system so TOPSIS is useful for the above methodology. Graphical techniques are useful only for the visual inspection of the system.

### 3.3.5 Final selection (Stage 3)

The different tools TOPSIS and two graphical techniques evaluation results are varying from each other. So it is depended on the user, which technique is more suitable to him for the optimal selection. After ranking the different systems, system with the 1st rank is not always preferable. There are some other constraints as shown in fig 3.13 are considered for the final selection of the FPLSC system.

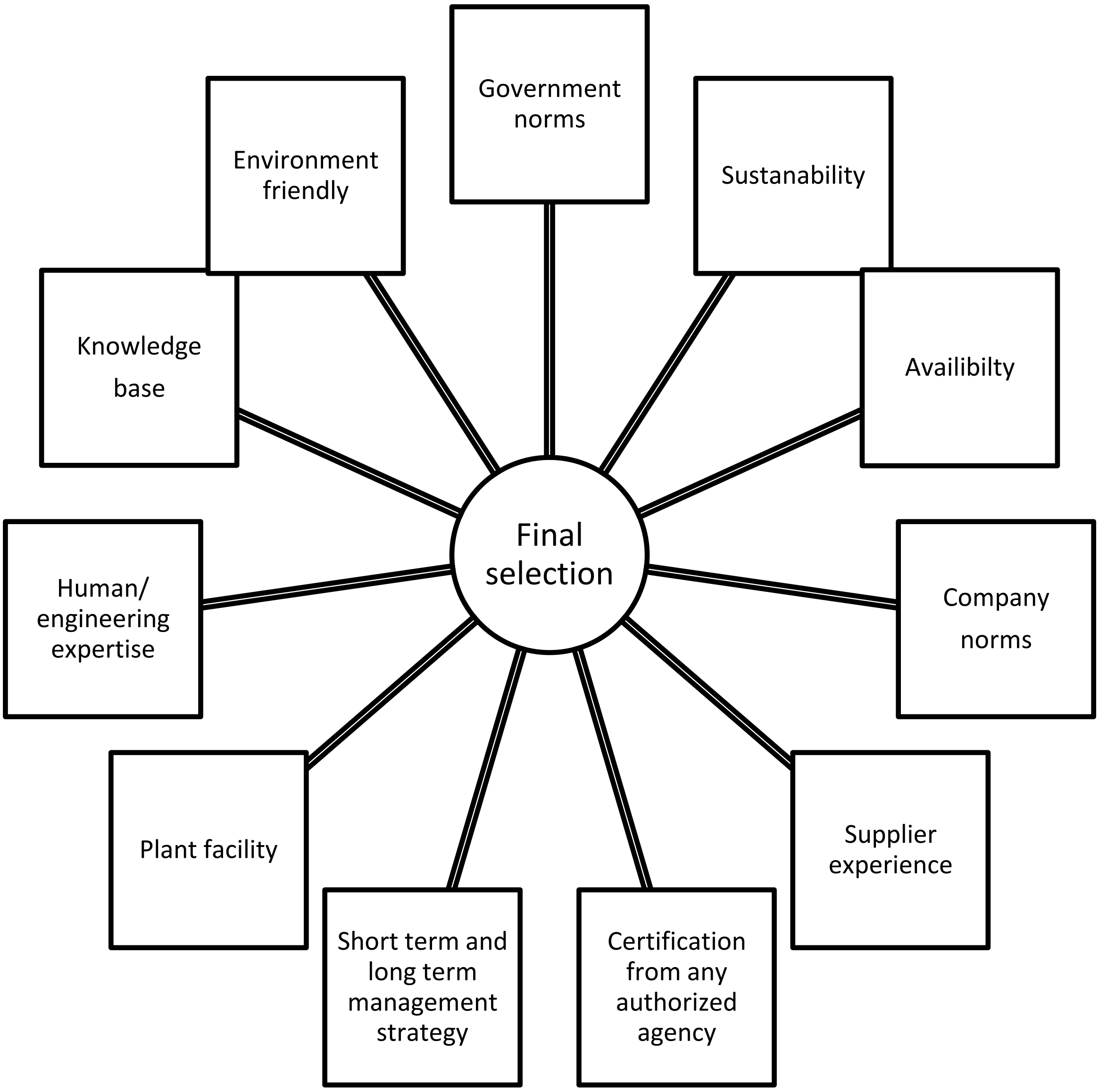

Fig 3.13 Constraints for the final selection of FPLSC

### 3.4 Step by step procedure

- Develop the cause and effect diagram for the identification of appropriate attributes for the selection and evaluation of the system.
- Collect the attributes relating to the causes that are found from the cause and effect diagram.
- Collect the comprehensive and exhaustive information about the each attribute for the precise coding of the attribute alternatives.
- There is no need of coding quantitative attributes. Their numerical values are directly used for comparison.
- Qualitative attributes are converted into quantifiable form using n-digit coding.

- The information finally arrived after coding of attributes is useful for evaluation and selection procedure.
- Apply elimination search to find out the limited number of attributes those are effected the selection more as per the requirements. Threshold values of these attributes are calculated or given by the team of experts for a particular application. Systems are selected those fulfill these values.
- A short list of accepted system is formed from the elimination search. Develop decision matrix in terms of attributes for accepted systems. Attributes are normalized for the comparison on the basis of across the attributes.
- Relative importance matrix for particular application is developed by the team of experts. So that the importance of particular attribute with respect to other is also taken into account while comparison.
- Weight vectors are calculated from the relative importance matrix to reduce the risk in inconsistency of relative importance values.
- Finally a weighted normalize matrix is developed for the accepted systems.
- TOPSIS, line graph and spider graph are the techniques those are useful for the selection, evaluation and ranking of the accepted system using information from the weighted normalize matrix.
- The results from the three techniques are not same so the selection of suitable technique is depended on the user as per his requirements.

A graphical representation of the methodology as shown in fig 3.14 is developed for the better understanding of the methodology.

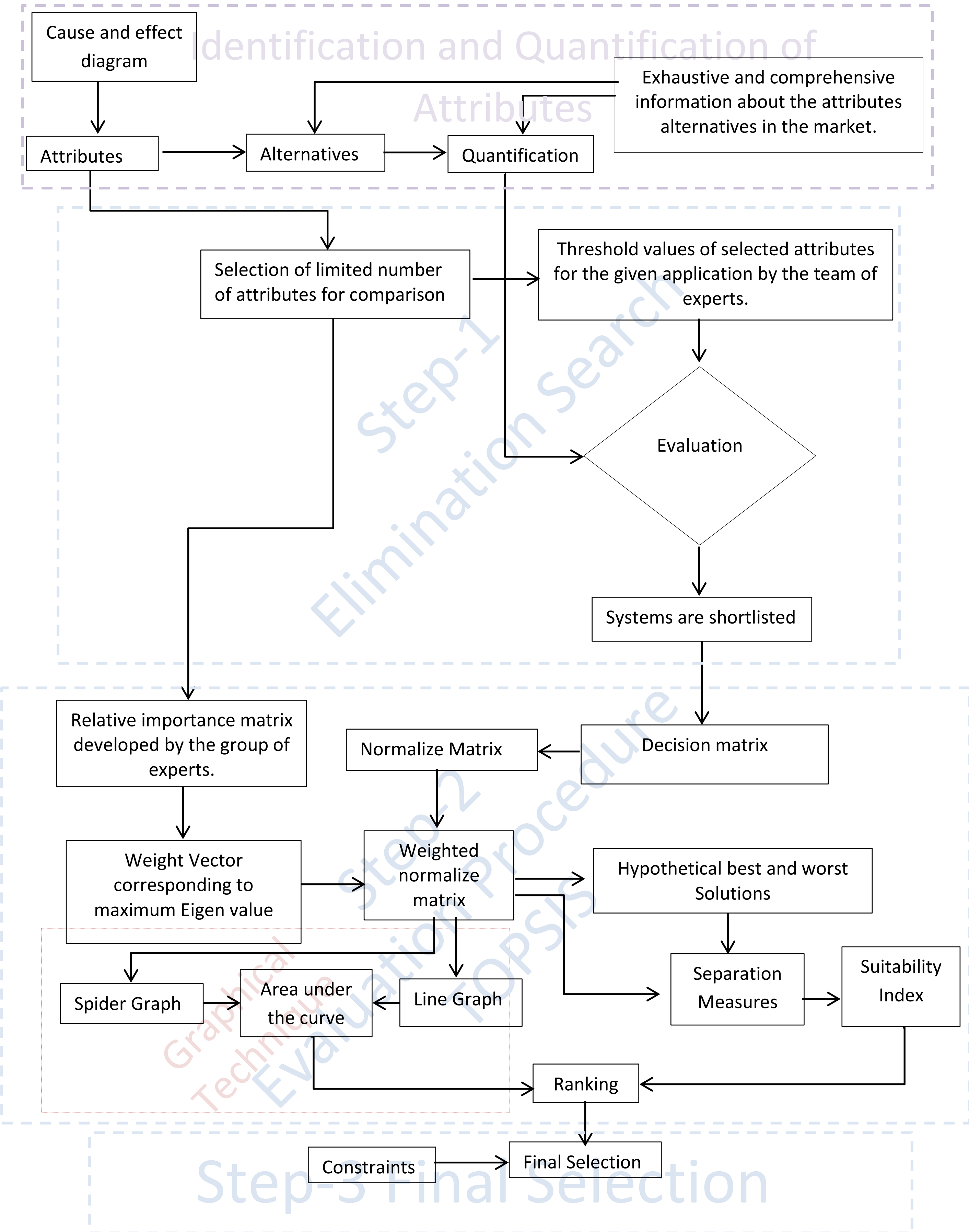


Fig 3.14 Graphical representation of selection approach

Multi attribute based selection procedure is developed for the selection of the available optimal FPLSC system. There are number of attributes are collected those are effect the selection of the system. On the basis of these attributes user classify the systems more precisely for the selection. Information develops from the quantification of attributes is useful to the manufacturer, designer and the user. A finite number of Systems are shortlisted from the available systems using elimination search based on attribute values. Systems are compared from the matrix developed in terms of attributes, taking into consideration of relative importance of each attribute with respect to other. TOPSIS and graphical techniques (line graph, spider graph) are used to rank the systems.

# Chapter 4
# Modeling and analysis of FPLSC

FPLSC uses in many industrial and domestic areas for low temperature heating applications. These collectors are widely used all over the world because of the simple in design and high reliability. A system performance is the combined effect of its constituents and the interactions between these constituents. Flat plate solar collector systems are need to be stable with the thermal conditions, environment conditions and chemical reactions. These characterstics are achieved by the comnbine effect of its constituents. The main components of the FPLSC are absorber plate, insulation, transparent cover, flow tube and the casing.Optical properties of the absorber effect the thermal performance of FPLSC are studied in [22, 23, 24, 25, 27, 61]. Performance of FPLSC is also effected by the design parameters of the absorber are studied in [17, 21, 26, 28]. Effect of thermal properties of material on the performance of FPLSC is studied in [16, 26]. Design parametrs of the flow tubes effect the thermal performance of the system as studied in [14, 15, 16, 27, 29, 30]. Optical and design properties of transparent cover effect the thermal performance of the system are studied in [14, 16, 23, 26, 27, 30]. Interaction between the absorber plate and glass cover efect the thermal performance of the system [21], [47]. Insulation material effect the thermal performance of the system [27], [61].

From the above literature review it is clear that the only thermal performance is evaluated by considering all structure constituents and interactions between the constituents.ther is no model is developed to evaluate the parameters like quality and reliability of the system a new approach is proposed for the evaluation of the parameters like quality and reliability of system considering all constituents and the interactions between the constituents.

## 4.1 **Identification of structural constituents and the interaction**

Optical peformance of the FPLSC depends on the transparent cover thickness, transparent cover tranmittance, number of transmittance cover, type of selective coating to reduce the reflection losses [14, 16, 23, 27]. Thermal performance of the FPLSC depends on the absorber plate material, shape, selective coating, thickness, bonding material,type of bondingand tube placement with respect to absorber [16, 17, 21,26, 27, 28, 29, 30]. T chermal performance of the FPLSC depend on the flow tube crossection, maetriall, tube diameter, tube thickness, tube spacing, tube arrangement [14, 15, 16, 27, 29, 30].

From the above information it is clear that to develop the model of FPLSC structure, a number of attributes are needed. A attempt is made to identify the different structural constituents of FPLSC contributing the system performance and arrange them into five subguops as shown in fig 4.1.

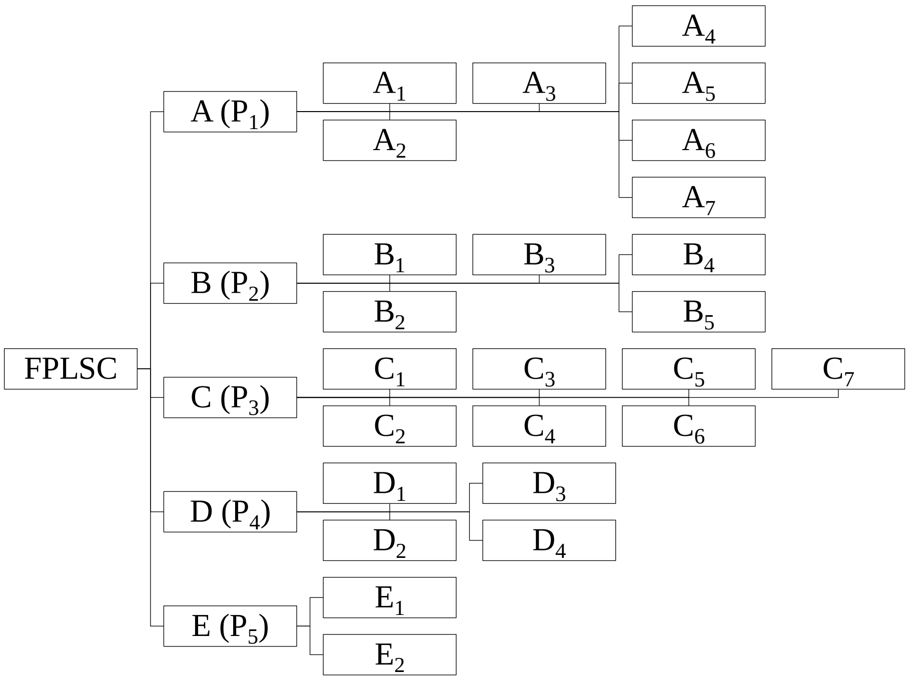


Fig 4.1 Structural constituents of FPLSC

A – Absorber plate, $A_1$ – Material, $A_3$ – Shape, $A_2$ – Selective coating Technique, $A_5$ – Type of selective coating, $A_4$–Thickness, $A_6$ – Tube placement with respect to absorber, $A_7$ - Bonding material,

B – Transparent cover, $B_1$ – Number of covers, $B_2$ – Selective coating, $B_3$ – Material,$B_4$ – Thickness, $B_5$ – Type of condition between absorber and cover

C – Tubes, $C_1$ – Tube cross section, $C_2$ – Material, $C_3$ – Arrangement, $C_4$ – Tube length, $C_5$ – Tube spacing, $C_6$ – Tube diameter, $C_7$ – Tube thickness

D – Insulation, $D_1$ – Back Insulation material, $D_2$ –Back insulation thickness, $D_3$ – Side insulation thickness, $D_4$ – Side insulation material

E – Casing, $E_1$– Casing thickness, $E_2$ – casing material

## 4.2 **Graphical representation of FPLSC**

Different constituents are identified about the FPLSC as shown in fig 4.1. An undirected graph is developed to show the interactions between the constituents in fig 4.3. A graph is represented by [V, E]. Here {V} = ($v_1$, $v_2$, . . . . .$v_n$) vertices of the graph and {E} = ($e_1$, $e_2$, . . . . $e_n$ ) represent the edges of the graph. In fig 4.3 subsystems are represented by the vertices of the graph and the interactions of the subsystems are represented by the edges of the graph. Directed graph are used where the one subgroup has the effect on other subgroup but the other subgroup has not the effect of that group or the subgroups has different effects on each other. Interaction between A and B represents the distance between absorber and transparent cover. Interactions between A and D is the distance between absorber and insulation. Interaction between A and C represents the type of bonding technique used for the bonding of absorber plate and flow tube. A, B, C and D are linked with E by mechanical links. This diagram helps in the better understanding of the structure. Different results can be retrieved from the graph if the mathematical representation of the constituents is given.

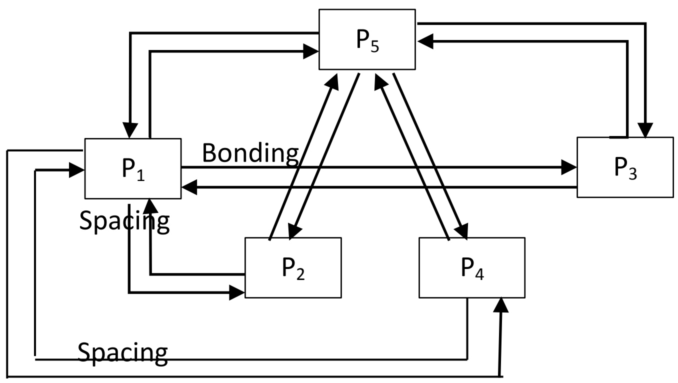


Fig 4.2 Directed graph of FPLSC structure

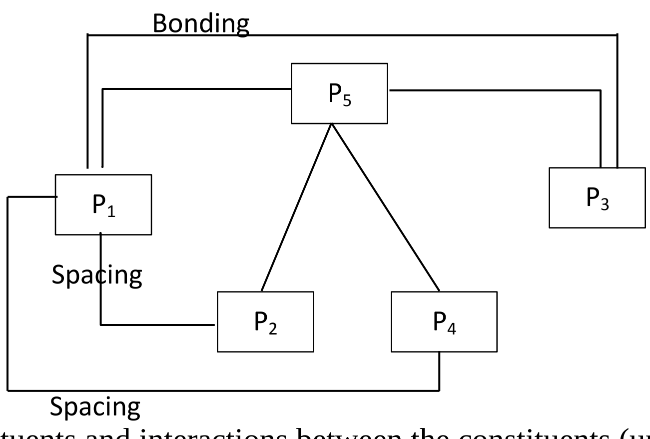

Fig 4.3 Constituents and interactions between the constituents (undirected graph)

**4.3 Matrix representation**

Graphical representation of FPLSC constituents and interaction between the constituents is used only for visual inspection. For to make it more useful information from the graph is represented in the form of matrix. A square matrix A = [$P_{ij}$] of order 5 is constructed, order depends on the number of subsystems. Here $P_{ij}$ represents the interaction of the $i^{th}$ system with the $j^{th}$ system. If the interaction present then put the value 1 and if the interaction is not present put the value 0. $P_{ii}$ is zero because of there is no self-loop of any subsystem. Matrix for the undirected graph shown in fig 4.3 is given below:

$$A = \begin{matrix} & 1 & 2 & 3 & 4 & 5 & \\ & \left[\begin{matrix} 0 \\ 1 \\ 1 \\ 1 \\ 1 \end{matrix}\right. & \begin{matrix} 1 \\ 0 \\ 0 \\ 0 \\ 1 \end{matrix} & \begin{matrix} 1 \\ 0 \\ 0 \\ 0 \\ 1 \end{matrix} & \begin{matrix} 1 \\ 0 \\ 0 \\ 0 \\ 1 \end{matrix} & \left.\begin{matrix} 1 \\ 1 \\ 1 \\ 1 \\ 0 \end{matrix}\right] & \begin{matrix} 1 \\ 2 \\ 3 \\ 4 \\ 5 \end{matrix} \end{matrix} \qquad (27)$$

4.4 FPLSC system characteristic matrix

Characteristic matrix B, for the graph developed for FPLSC is written as [PI-A]. Where P is the variable representing the FPLSC and I is the identity matrix.

$$B = \begin{bmatrix} P & -1 & -1 & -1 & -1 \\ -1 & P & 0 & 0 & -1 \\ -1 & 0 & P & 0 & -1 \\ -1 & 0 & 0 & P & -1 \\ -1 & -1 & -1 & -1 & P \end{bmatrix} \qquad (28)$$

As in matrix B all the FPLSC subsystems are assumed to be identical but all these subsystems have different characteristics depending on the various parameters. Also only the information about the presence of interactions is given but the degree of influence is not given. So to include this type of information a FPLSC variable characteristic matrix is proposed.

**4.5 FPLSC system variable characteristic matrix (VCM-FPLSC)**

This matrix is able to represent the different characteristics of different subsystems. The degree of influence of the different interactions is also represented by the matrix. To develop this type of matrix graph in fig 4.2 is used. Consider a square matrix C with off diagonal elements $P_{ij}$, represent the interaction between the subsystems. Another matrix D is considered with diagonal elements $P_i$ representing the different subsystems of FPLSC as shown in fig 4.2. VCM-FPLSC is represented as H = [D − C]

$$H = \begin{bmatrix} P_1 & -P_{12} & -P_{13} & -P_{14} & -P_{15} \\ -P_{21} & P_2 & 0 & 0 & -P_{25} \\ -P_{31} & 0 & P_3 & 0 & -P_{35} \\ -P_{41} & 0 & 0 & P_4 & -P_{45} \\ -P_{51} & -P_{52} & -P_{53} & -P_{54} & P_5 \end{bmatrix} \quad (29)$$

The above VCM-FPLSC is useful to represent complete information about the subsystems and the interactions between the subsystems of any industrial FPLSC system. The information is useful for analysis, design and development of new FPLSC systems at conceptual stage. A powerful tool is derived from the matrix through its determinant called variable characteristic FPLSC polynomial (VC-FPLSC). This represents the complete system, taking into account of the subsystems and the interaction between the subsystems. The determinant of the H matrix contains both positive and negative values. It will give complete information about the system until the multinomial in symbolic form. But if the subsystems and interactions are replaced by numerical values, information is lost because of negative signs. So VC-FPLSC is useful to give information only when $P_i$ and $P_{ij}$ are in symbolic form. To overcome the limitation of VC-FPLSC another term FPLSC system variable permanent matrix (VPM-FPLSC) is introduced.

**4.6 Composite system variable permanent matrix**

For to represent the FPLSC system using unique and comprehensive model, a new entity permanent and permanent matrix is proposed. The permanent matrix for the five subsystems FPLSC is defined as

$$P = \begin{bmatrix} P_1 & P_{12} & P_{13} & P_{14} & P_{15} \\ P_{21} & P_2 & P_{23} & P_{24} & P_{25} \\ P_{31} & P_{32} & P_3 & P_{34} & P_{35} \\ P_{41} & P_{42} & P_{43} & P_4 & P_{45} \\ P_{51} & P_{52} & P_{53} & P_{54} & P_5 \end{bmatrix} \quad (30)$$

The above matrix is developed by considering all the subsystems are interacted with each other. But there are some subsystems are not linked in FPLSC system shown in fig 4.2.1. The variable permanent FPLSC (VPM-FPLSC) matrix represents the FPLSC system shown in fig 4.2 is given by:

$$E = \begin{bmatrix} P_1 & P_{12} & P_{13} & P_{14} & P_{15} \\ P_{21} & P_2 & 0 & 0 & P_{25} \\ P_{31} & 0 & P_3 & 0 & P_{35} \\ P_{41} & 0 & 0 & P_4 & P_{45} \\ P_{51} & P_{52} & P_{53} & P_{54} & P_5 \end{bmatrix} \quad (5)$$

The diagonal elements of the VPM-FPLSC represent the subsystems of FPL and the other terms represent the interaction between the subsystems. This model eliminates the drawback of the VC-FPLSC. This model can handle the information in quantitative form without loss of any information.

### 4.7 Permanent function representation

Matrix and graphical representation are not unique as these are changed by changing the labeling of nodes. So to make a unique representation of the FPLSC systems, a permanent function of the matrix VPM-FPLSC is proposed. Permanent function is obtained similar to the determinant of the matrix. The only difference is that the negative signs in the determinant are replaced by the positive sign to stop the loss of information in case of quantitative representation of FPLSC. Maximum number of terms in the permanent function depends on the number of subsystem in which system is divided. If there is n number of subsystems then the maximum number of terms formed is n!. These terms depend on the interaction between the subsystems. As the interactions between the subsystems are reduced, the number of terms also reduces. So in the case of FPLSC which is divided into five subsystems, maximum 120 terms can be present in permanent function. But as the interaction between the subsystems are not much. These terms are reduced to 26 as give below:

$$\begin{aligned} \mathrm{Per\,(E)} = {} & P_1P_2P_3P_4P_5 + P_1P_2P_3P_{45}{}^2 + P_1P_2P_4P_{35}{}^2 + P_1P_3P_4P_{25}{}^2 + P_2P_3P_4P_{15}{}^2 \\ & + P_2P_3P_5P_{14}{}^2 + P_2P_4P_5P_{13}{}^2 + P_3P_4P_5P_{12}{}^2 \\ & + (2P_3P_4P_{12}P_{25}P_{51} + 2P_2P_3P_{14}P_{45}P_{51} + 2P_2P_4P_{13}P_{35}P_{51} + 2P_3P_4P_{52}P_{21}P_{15} \\ & + 2P_2P_3P_{54}P_{41}P_{15} + 2P_2P_4P_{53}P_{31}P_{15}) \\ & + \left(P_2P_{45}{}^2P_{13}{}^2 + P_2P_{14}{}^2P_{35}{}^2 + P_3P_{45}{}^2P_{12}{}^2 + P_3P_{14}{}^2P_{25}{}^2 + P_4P_{12}{}^2P_{35}{}^2 \right. \\ & \left. + P_4P_{13}{}^2P_{25}{}^2\right) \\ & + (2P_2P_{13}P_{35}P_{54}P_{41} + 2P_3P_{12}P_{25}P_{54}P_{41} + 2P_4P_{12}P_{25}P_{53}P_{31} \\ & + 2P_2P_{53}P_{31}P_{14}P_{45} + 2P_3P_{21}P_{14}P_{45}P_{52} + 2P_4P_{21}P_{13}P_{35}P_{52}) \end{aligned}$$

26 terms

These terms are also written by the visual inspection of the system. A permanent function contains maximum (N+1) groups. So a system of five subsystems contains 6 groups as shown below:

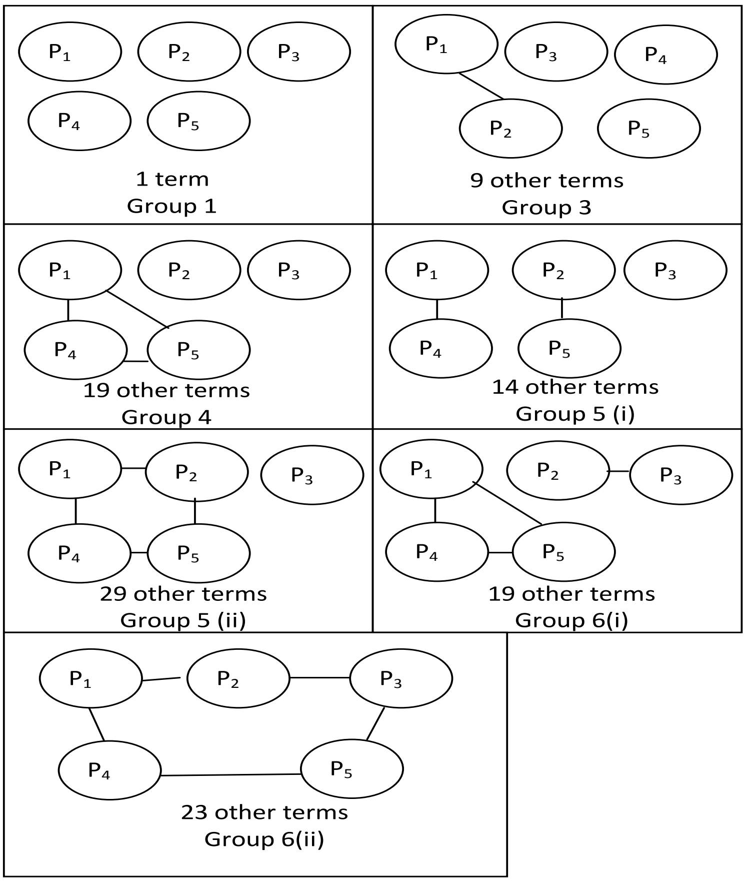


Fig 4.4 Graphical representation of permanent function of P matrix

Group 1 contains only one term of five isolated subsystems.

Group 2 is absent because subsystem has no interaction with itself.

Group 3 contains ten terms. In each term two subsystems are forming a loop ($P_{ij}^2$) and the other three are isolated.

Group 4 contains 20 terms. In each term three subsystems make a loop and other two are Independent.

Group 5 is divided into two groups 5(i) and 5(ii).

Group 5(i) contains 15 terms. Each term contain two groups of two subsystem loops and one independent subsystem.

Group 5(ii) contains 30 terms. In each term four subsystems make a loop and the other one is independent.

Similar to Group 5, Group 6 is divided into two subsystems 6(i) and 6(ii).

Group 6(i) contains 20 terms. In each term three subsystems make a loop and the other two make a loop.

Group 6(ii) contains 24 terms. In each term all subsystems make a loop.

The above representation is for the system in which all the subsystems are interacted with each other. But in the case of FPLSC all the subsystems are not interacted with each other. So the different groups and the number of terms in each group for FPLSC is shown in fig.4.7.2.

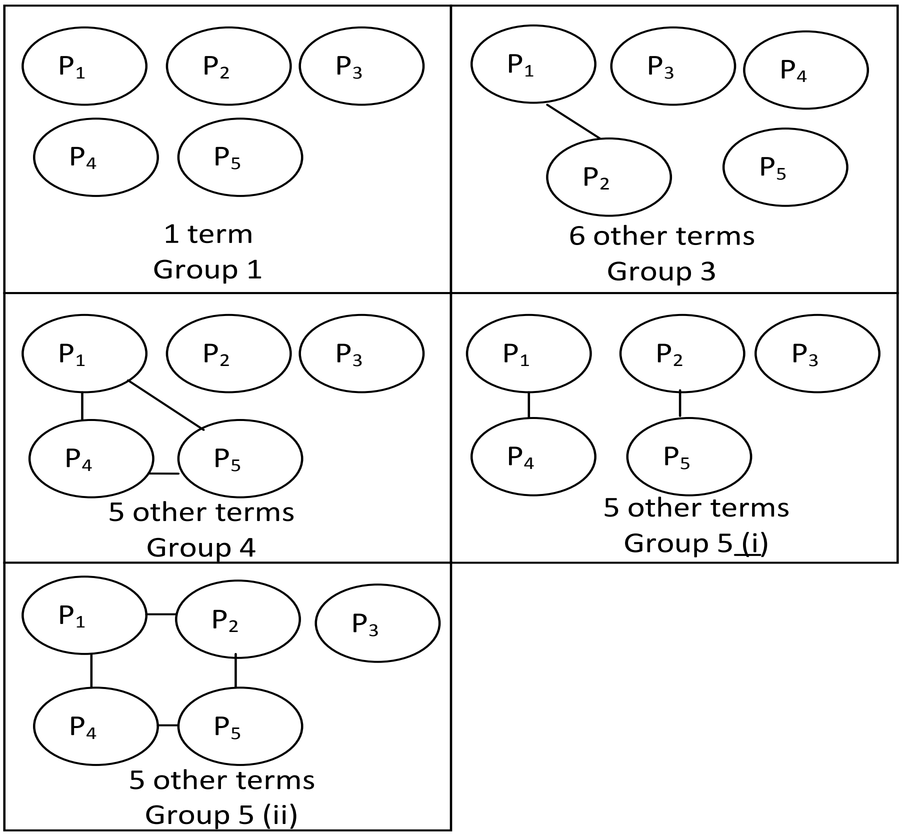


Fig 4.5 Groups present in FPLSC structure

The information is not lost in the permanent function if the constituents and interactions are replaced by numerical values. Due to which it is useful to evaluate the different properties of the system like reliability, quality etc.

## 4.8 **Evaluation of $P_i$**

$P_i$ values are evaluated as same to per (P) function. Interactions between the constituent of subsystem are identified. Then make the digraph of the subsystem and make the variable permanent matrix $EP_i$ for the subsystem. Then develop the $P_i$ = per($EP_i$).

## 4.9 **FPLSC analysis**

Step by step procedure for the analysis of FPLSC is given below:

- Select the desired FPLSC. Study the subsystems of the system and the interaction between the subsystems.
- Develop a graph representing the FPLSC subsystems and the interaction between the subsystems.
- Develop the matrix and multinomial from the graph.
- Evaluate the diagonal elements of the variable permanent matrix. This is done by evaluating the permanent function of the subsystems.
- Identify the function/values of off diagonal elements. Permanent functions of the subsystems.

Using the above procedure different subsystems can be divided further into subsubsystems and different graph, matrix and permanent function can be obtained.

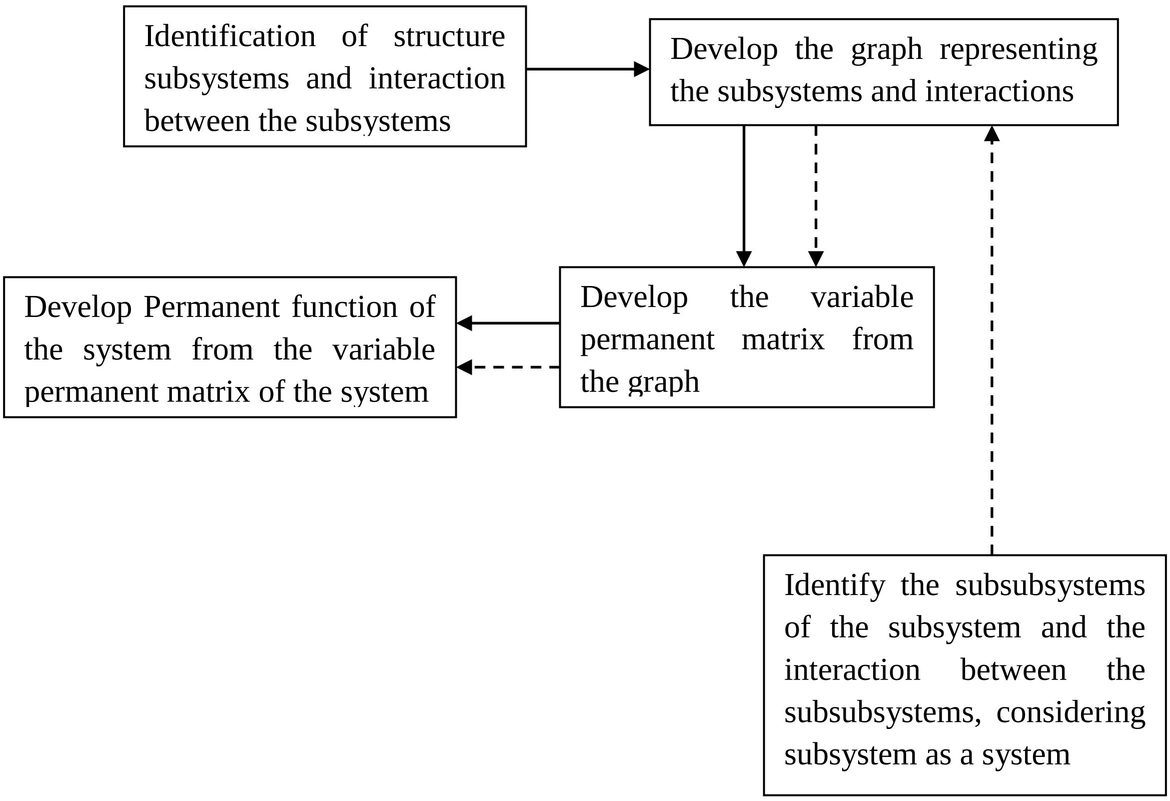


Fig 4.6 Graphical presentation of structural analysis of FPLSC

## 4.10 **Comparison of different FPLSCs using permanent function**

Different FPLSCs are developed from different type of constituents and the interaction between the constituents. As the permanent function represents each constituent and interaction between the constituents is able to compare the FPLSCs. Two FPLSC systems are identical if number of terms is equal, number of terms in each group is equal and the value of each term is equal. So a FPLSC system characterize as:

$$[(J_1^P/J_3^P/J_4^P/J_{51}^P/J_{52}^P)(V_1^P/V_3^P/V_4^P/V_{51}^P/V_{52}^P)]$$

Here $J_i^P$ represent the number of terms in the i$^{th}$ grouping. $J_{ij}^P$ represent the number of terms in the j$^{th}$ subgroup of i$^{th}$ grouping. $V_i^P$ represents the numerical value of the i$^{th}$ grouping. Similarly $V_{ij}^P$ represents the numerical value of j$^{th}$ subgroup of i$^{th}$ grouping.

**4.11 Usefulness**

This methodology helps in to develop a variety of FPLSCs providing optimum performance properties under different industrial applications. This approach is useful to get information whether the system characteristics are represented in qualitative form or quantitative form. In qualitative form, permanent function is useful to differentiate the different FPLSCs. This methodology makes the system possible to represent in quantitative form. The quantitative form is much useful to drive different results from the permanent function.

In this structure analysis of the FPLSC is carried out. The different performances and other characteristics of the FPLSC depend on the constituents and the interaction between the constituents. A model is developed in terms of permanent function which is very useful for comparison and analysis of FPLSC. This permanent function takes care of the effect of all constituents and interaction between the constituents. Due to which it is useful for the analysis of FPLSC. This model become very useful if the system properties are quantified as it represents the system in mathematical form.

A new approach of literature review of FPLSC is proposed which is very useful for the researchers, industrialists, manufacturers, designers. In this IM is formed from the information available in the different publication data.

- The amount of research work done on each individual attribute also clearly calculated from the IM, with the help of which the gap analysis is carried out efficiently and effectively.
- From the information matrix papers related to the particular attributes are sorted out and get the information about those particular attributes.
- Spider graph is useful tool to get the more suitable paper of interest on the basis of attributes.
- With this attribute based literature review the knowledge related to performance, design and manufacturing is easily obtained from the IM.
- This IM is a permanent source of knowledge and need to be updated so that anyone takes more benefit from this database.

Multi attribute based selection procedure is developed for the selection of the available optimal FPLSC system. There are number of attributes are collected those are effect the selection of the system.

- On the basis of these attributes user classify the systems more precisely for the selection.
- Information develops from the quantification of attributes is useful to the manufacturer. In quantification of attributes manufacture get the idea about the relative values of attribute alternatives which helps in the selection of suitable alternative of attribute.
- Information develops from the quantification of attributes is useful to the designer. Similar to the manufacturer, designer also gets the values of different design alternative values which help in the design improvement.
- Information develops from the quantification of attributes is useful to the user in the selection of system. As the values of different attributes are given, user selects the system as per his requirement.

- Elimination search shortlist the systems from the available data those are used for the given application. This reduces the time of inspecting all systems.
- TOPSIS and other graphical techniques are used for the optimum selection from the selected systems. The results from the TOPSIS and other graphical techniques are not same. Line and spider graph techniques are more consistent with each other.
- Relative importance of the desired attributes is also taking into the consideration.
- Sensitivity analysis is useful to see the effect of different attributes on the ranking of the system. This helps the manufactures and designers to understand which attribute is concerned more while manufacturing or designing.
- Gives guide line to development of new design of the system.
- A number of system designs can be described as per the alteration in the parameters of the system and at the same time evaluation of these design can be done.

Modeling and analysis of the FPLSC structure

- A permanent function and matrix is developed for FPLSC which include every constituent and interactions between the constituents. There is unique permanent function for every different FPLSC system. This helps in the evaluation of the system for different prospective as the system behavior depend on its structural constituents and the interaction between the constituents.

Future Scope:

- A permanent database can be developed in the form of information matrix. Software can be developed to make it available on the internet. This database is flexible with the addition of any new literature paper.
- A database of characterization of FPLSC systems in terms of attributes can be developed in the selection approach. This helps the user to select the system easily.
- A proper coding of all attribute alternatives can be developed in the selection approach. This helps in improving the accuracy level for the selection of the system.
- A computer program for the selection approach can be developed for to carry out all these calculations.
- This selection approach can be applied on the solar collectors, for the selection of suitable solar collector for a given application.
- From the selection approach, procedure for the selection of any system in any other field can be developed.

- Numerical coding of constituents and interaction between the constituents for different parameters of FPLSC can be developed which is useful to calculate the system's different parameters in mathematical form. These values are used to compare the different alternatives.

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