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A Novel Methodology of Literature Review of a Flat Plate Liquid Solar Collector

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A B S T R A C T

In this study, a literature review in the area of flat plate liquid solar collector (FPLSC) is carried out using an effective and efficient approach. The approach is based on research issues and other attributes those affect the system performance. These issues and attributes are collected from the presently published literature. Attributes can be classified into different categories for better handling, storage and identification. In case of FPLSC, attributes are classified as general, operational, environmental, type of application, type of work, instruments used and others. An information matrix (IM) is developed between present literature and the attributes. It is shown that the IM is a powerful source to derive knowledge from the database of research publications using different tools of excel software and is very useful to the industrialists, designers and researchers. Moreover, the academic value of different papers and attributes is obtained in this study. By comparing information obtained from IM and cause & effect diagram the gaps in the existing literature are easily identified. The IM is easily stored in computers on excel sheet. The IM being flexible and comprehensive become an archive of FPLSC and a permanent asset to be updated and used in future research work.

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1. Introduction

The use of solar energy for different applications is imperative now-a-days for sustainable future. The energy from sun can be utilized for plentiful thermal energy applications. Various solar collectors are used for different applications like water desalination in Bhargva and Yadav [1], steam generation in Swanepoel et al. [2], water heating in Sadiq et al. [3], refrigeration and air conditioning in Raut and Kalamkar [4]. Hashemian and Noorpoor [5] proposed a new design of hybrid system consisting of a steam power cycle, dual effect cooling and a provision for hydrogen and ammonia production. The results from exergy analysis indicated an exergy efficiency of 17.97% and an energy efficiency of 83.65%. Hashemian and Noorpoor [6] also designed a bio-mass and solar assisted multi-application system. The application of multi-effect distillation for seawater desalination is also integrated to the applications mentioned in Hashemian and Noorpoor [5]. The results indicated an increase in exergy efficiency from 14% to 16.53% using a multi-criteria optimisation technique. To understand the recent advancement in this field and to continue further research work, a comprehensive literature review is indispensable. Literature review is the way to get the information from the data available in the form of research papers in a particular research field. Knowledge is extracted from the information to identify research gaps which becomes the basis of further research work. Literature review represents the history and advancements in a particular research field. This includes what is being done in that field, what is going on in that field, and what are the basic attributes of the particular field. No one does research in any field until the history and the extent of work done on different issues and attributes related to research field are not known. So it is very important part or basic need of the research. Alghoul et al. [7] and Vengadesan et al. [8] reviewed the application of different materials used in the development of a FPLSC and discussed the methods employed to improve its thermal performance. Gorla et al. [9] represented a new two dimensional methodology to evaluate performance and calculate the heat losses from FPLSC. Aghakhani et al. [10] performed a numerical simulation study using finite element method to analyse the effects of using a spiral pipe in a FPLSC. An experimental test rig is also developed and tested to validate the theoretical findings from the simulation. The results showed an increase in water temperature and heat loss coefficient which is in good agreement with the simulation results. Yeh et al. [11] modified the design of absorber plate and risers arrangement for improving the efficiency of a FPLSC. The aspect ratio was varied to understand the effect by keeping the absorber area constant. The results showed increase in collector efficiency with increase in collector aspect ratio. A parallel flow flat-plate solar collector's absorber plate temperature distribution is examined using 1-D and 2-D steady-state conduction equations with heat generation. The isotherms and performance curve for 1-D analysis, expressed in terms of Ɛ-NTU relationship differ slightly from that of 2-D analysis, especially under low mass flow rate conditions according to the comparison of 1-D and 2-D results in Kazeminejad [12]. Al-Tabbakh et al. [13] performed numerical simulation of a FPLSC and solved the governing equations using finite difference method. The results showed heat transfer coefficient of FPLSC as a direct function of solar intensity and fluid mass flow rate. Srithar et al. [14] used fibre reinforced plastic FPLSC to evaporate water in tannery effluent. The results showed increase in evaporation rate with increase in solar intensity and wind speed. Also, the evaporation rate increased with decrease in relative humidity and mass flow rate. Kumar et al. [15] observed an increase in thermal efficiency of FPLSC by using liposomes nanoparticles. It was also observed that the exergy efficiency was directly dependent on the weight concentration of nanoparticles. Freegah et al. [16] developed a FPC with elliptical pipes and longitudinal channels on the flat plate along with fins. The experimental and theoretical investigation showed that with the modifications the thermal efficiency and the mass flow rate of fluid were increased by 22% and 7.9% respectively in comparison to the conventional flat plate collector. Sivakumar et al. [17] integrated a flat plate collector to a double slope solar still and observed 74% increase in distillate output with 3.02 l/day. Abu-Zeid et al. [18] investigated the effect of nanofluids (CNT and ethylene glycol) on the flat plate collector and parabolic concentrator based domestic solar water heaters. The results showed enhancement in thermal efficiency by 64% and 80% using ethylene glycol and a reduction in CO_2 emissions by 31 kg/d and 39 kg/d were observed for flat plate collector and parabolic trough concentrator respectively. Jovijari et al. [19] theoretically analysed and performed exergy analysis on a crude oil desilting system using flat plate collectors. The results showed a comprehensive 83% reduction in CO_2 emissions in comparison to crude oil desalination using indirect fired heaters. Ajeena et al. [20] experimentally investigated the effect of silicon carbide (SiC) nanofluid on the efficiency of FPLSC. The experimental results showed 30% improvement in thermal conductivity of SiC incorporated heat transfer fluid and maximum thermal efficiency to approximately 77%. Garcia-Rincon et al. [21] exhaustively reviewed applications of various nanofluids in solar water heaters and their effect on the thermal efficiencies of different solar collectors. The results showed a maximum 35% improvement in thermal efficiency of flat plate collectors using nanofluids. Shemelin et al. [22] worked on the design changes in flat plate collector to enhance its performance by reducing heat losses from front side of the collector. Alkhafaji et al. [23] modified a flat plate collector with different riser pipe crossections (elliptical and semi-circular) and channel absorber plate. The above modifications resulted in 13.7% increase in thermal efficiency of the collector. Chilambarasan et al. [24] used grooved absorber plate and aluminium oxide nanofluid to expedite heat transfer rate and increase the thermal efficiency of the flat plate collector. The nanofluid is used in different weight concentrations and mass flow rates. The results showed that maximum efficiency at 0.2% weight concentration and mass flow rate of 0.036 kg/s. The application of some other nanofluids like zirconium oxide-distilled water mentioned in Ajeena et al. [25], zirconium dioxide-silicon carbide with distilled water hybrid nanofluid mentioned in Ajeena et al. [26], and polyethylene glycol-iron oxide nanofluid mentioned in Akram et al. [27] resulted in the improved heat transfer rate and thermal efficiency of flat plate solar collector.

The current literature is mainly focused on the design modifications in the flat plate collector to enhance its thermal performance. The most recent research works mainly emphasised on the application of various nano-fluids to expedite the energy transfer rate and boost the thermal efficiency of the system. The theoretical analysis of the flat plate collector system is also studied by many researchers to find out heat loss to the surroundings and worked on reducing it to maximise thermal efficiency of the system. The research works pertaining to flat plate collector primarily focused on the theoretical and experimental investigations to enhance its performance. But, no research work is done on developing a strong database of attributes or parameters affecting the performance of the FPLSC system. In the present work, a novel methodology is presented to ease down the tedious process of literature review and to precisely locate the research paper as per the user requirements. This methodology will help the researchers to get complete information about the background, current state, and recent advancements in the research regarding FPLSC. In this methodology, the research data from various research papers are stored in one location forming an exhaustive database. This database will provide all the technical information required to design and develop a FPLSC for a particular application. With the research work progressing worldwide, the database could be updated from time to time to make it more reliable and informative. This comprehensive database is very beneficial for any researcher working on FPLSC to extract the information they need about any parameter and help them identify research gaps as well. It is also useful for the manufacturers as they will get the desired information regarding different performance parameters, energy storage materials, and economics concerning the FPLSC.

2. Methodology

2.1. Characterization of paper and identification of attributes

Any research paper outlines one or more research field parameters to see the intended results. Therefore, each research study is defined by the following research area parameters:

$$p_j = A_1, A_2, A_3, \ldots\ldots\ldots A_i, \ldots\ldots A_m \tag{1}$$

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 related to the research field. Discovering characteristics for the paper's characterisation is necessary. These characteristics are compiled from research articles and information found in books on the subject.

2.2. Coding scheme

Since these characteristics are qualitative in nature, a team of specialists numbered them on an interval scale of 0 to 5 as indicated in Table 1 to convert the depth of information found in various research publications regarding these characteristics into quantifiable form.

Table 1. Quantification of attributes

Amount of work	Code
Very high	5
High	4

Average	3
Low	2
Very low	1
No	0

In order to provide information regarding the amount of work done on each attribute in the paper, each attribute in the paper's characterization was replaced by a numerical number between 0 and 5, as shown below:

$$p_j = A_1, A_2, A_3.....A_i,......A_m \quad (2)$$

$$Here, p_j = A_1, A_2, A_3.....A_i,......A_m \quad (3)$$

$$0 \le A_1, A_2, A_3.....A_i,......A_m \le 5 \quad (4)$$

2.3. Matrix formation

The qualities can now be measured by simply adding the numerical values which the property occupies in the research papers. Adding the numerical values occupied by different qualities also yield the total amount of work completed in that particular paper. This kind of information reveals the history of the attributes, indicating which attribute have come under the most and the least amount of investigation. The table 2 shows how the content is scrutinised to develop the information matrix m x n, where m represents the total number of qualities and n represents the total number of papers. The representations in table 2 is very convenient and effective in managing this type of information. The columns represent the papers identified on the basis of research inclination and rows represent the particular attributes in the research paper on which attention is focused. Attributes are the design, and operating parameters that directly affect the performance and other behaviours of the system.

2.4. Knowledge from the matrix

The matrix is developed on an excel sheet as different options and tools in the excel software helps in gathering information from information matrix in less time. The following knowledge is extracted from the information matrix using excel software.

- These sigma forms as shown in fig.1 give knowledge about the amount of work done on each attribute in a particular paper. Each row total gives the total amount of research work done on that attribute till now and each column total represents amount of research work done in that particular paper.
- Sorting is used to get information quickly about the attributes with maximum and minimum work done in the paper. This helps in the comprehension of important attributes as well as in defining the study field and highlighting research gaps.
- Attributes can be clubbed together into some small number of groups in case of large number of attributes. So that particular attribute could be identified easily.
- Attributes studied till now in a particular research field are collected together in a single matrix.
- Information about the change in attribute of interest about a research field with time.
- It gives information about research inclination in the flat plate collectors like theoretical modeling and experimental investigation.

2.5. 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 each paper in terms of attributes is represented in the IM, a spider graph is easily applied to get more useful paper. Table 3 shows that there are five identified parameters of researcher's area of interest investigated in three research papers that are presented in the information matrix from which table 3 is developed.

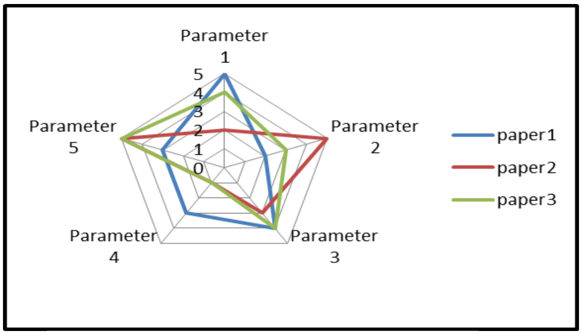


Figure 1. Spider graph

A spider graph generated between these papers vs.

Table 2. Contents of information matrix

parameters as shown in Fig.1 which makes it easy to

PAPER / ATTRIBUTE	P_1	P_2	_	_	P_j	_	_	P_n	SUM
A_1								$\sum a_{1j}$	$\sum a_{1j}$
A_2								$\sum a_{2j}$	$\sum a_{2j}$
_									_
_									_
A_i					A_{ij}				$\sum a_{ij}$
_									_
A_m									$\sum a_{mj}$
Sum	$\sum a_{i1}$	$\sum a_{i2}$	_	_	$\sum a_{ij}$	_	_	$\sum a_{in}$	

Table 3. Paper characterisation 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

compare the research papers. In the spider graph, each paper is represented by a different coloured line. Five corners represent the five parameters. From the graph it is clear that paper 1 is best as per parameter 1 and 4. Paper 1 and paper 3 are best as per parameter 3. Paper 2 is best as per parameter 2 and paper 2 and are best as per parameter 5. Area enclosed by each colour line gives the total amount of work done. In IM, a large number of attributes are collected on which work is done by various researchers. So this gives the information about what is done in the research field. To identify the research gaps, information required is the actual number of attributes relating to the research field. A cause and effect diagram is also developed as shown in Fig.2. The cause and effect diagram represents different causes (attributes) affecting the research field. The various factors influencing these attributes and characteristics are also included in this diagram in order to make it more elaborative and exhaustive for the users.

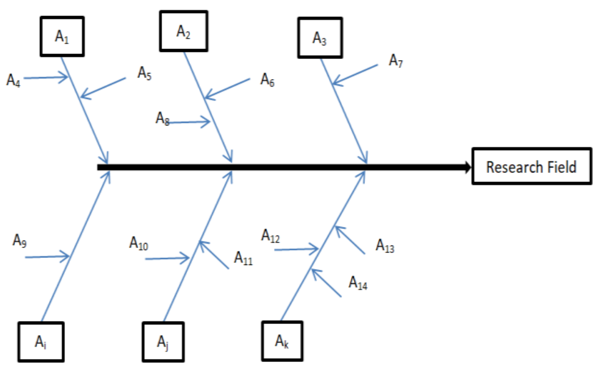


Figure 2. Cause and effect diagram

A_1, A_2, A_3, - - - - -A_i - - - - - A_k be the attributes. Research gaps are identified from the 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.

2.6. Excel tools to derive information from the IM

Auto sum is used for the summation of the different cells. Different types of sorting are used to get the information from the IM are shown in Table.4.

Table 4. Steps for sorting in Excel

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 total	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

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

2.7. Characteristics of IM

Matrix is easily developed and stored in the form of excel sheet. This becomes a permanent source of knowledge and can be accessed any time. It is flexible to the addition of new research paper as there is just a new column created in the matrix corresponding to that paper so if someone updates IM as per their requirements by adding the papers of their interest. Moreover, the IM become more informative as the number of papers increases. It is flexible to the addition of new attributes as it creates a new row corresponding to the attribute in the IM.

3. Implementation of methodology

3.1. Characterization and identification of attributes

Characterization of papers on FPLSC is done as per section 2.1. Attributes about FPLSC are identified in the same way as discussed in section 2.2. Some of the attributes identified are on the basis of the literature review mentioned in Kumar and Agrawal [28]. Gao et al. [29] developed a flat plate solar collector with vacuum inside for steam generation. Jiang et al. [30] performed thermal modelling on a flat plate solar collector consisting of a movable plate with v-shaped corrugations. Mohseni-Gharyehsafa et al. [31] used twisted tapes in a flat plate solar collector and analysed their effect on collector efficiency, Nusselt number and other performance parameters. Gorla et al. [9] used 2-D finite element model to study the effect of different parameters like fluid flow, tube diameter, tube spacing, number of glass covers on the outlet temperature and efficiency. Wang et al. [32] experimentally investigated the impact of environment related parameters, operational parameters, and collector area on the thermal performance of a flat plate collector. Yeh, H.-M et al. [11] made calculations about the effect of number of tubes on the efficiency of FPLSC keeping collector area constant. Ahmadlouydarab et al. [33] performed an experimental comparative study of a flat plate collector and a cylindrical solar collector. Kazeminejad et al. [12] solved 1-D and 2-D heat exchange equations using finite volume method and compared their results. Luminosu et al. [34] analysed the variation of outlet temperature with change in efficiency, solar irradiation, flow rate, specific heat of fluid and collector area with the help of a new program “Temp” used in digital simulation. Srithar et al. [14] used FPLSC as effluent evaporation system and experimentally investigated the effect of humidity, effluent concentration, wind speed, mass flow rate and solar irradiation on the evaporation rate. Badran et al. [35] observed an increase in water production rate of solar still using FPLSC as the component of the system. Effect of parameters like water depth and direction of solar still on the water production rate also studied in the paper. Aref et al. [36] experimentally investigated the effect of using closed loop heat pipe in the evaporation and condensation portions of a flat plate solar collector on its thermal efficiency. Manickavasagan et al. [37] experimentally studied the effect of different fluids used in FPLSC on its performance. Sharma et al. [38] experimentally enhanced the performance of a flat plate collector using circle shaped and trapezoid shaped corrugations on absorber plate. Metzger et al. [39] observed the effect on water production with change in parameters like ambient temperature, solar irradiation, type of fluid (tap or saline water) and operation mode (still alone for 24 hours, still with FPLSC for 24 hour and still with FPLSC for 8 hours of sunshine). Heat loss coefficients of FPLSC are evaluated for different absorber emissivity, tilt angle and ambient temperature in Sekhar et al. [40]. Effect of parameters like number of glass covers, wind load, absorber emissivity on the upward heat transfer coefficient is theoretically evaluated taking absorption in transparent cover under consideration in Akhtar and Mullick [41]. Bhargva and Yadav [42] analysed the shading effects of glass cover on the performance of a solar still. The optimum performance of an evacuated tube collector integrated to a solar still is obtained when the collector is inclined at an angle equalling latitude of the location studied by Bhargva and Yadav [43]. An experiment is performed to evaluate the effect of different selective coatings on FPLSC performance at different solar irradiation and tilt angles studied by Madhukeshwara and Prakash [44]. A simulation is performed to calculate the useful energy output from the coloured absorber and the amount of auxiliary energy required on the basis of location, month and amount of solar irradiation studied by Kalogirou et al. [45]. Similarly Dorfling et al. [46], Vejen et al. [47], and Kundu et al. [48] noticed the effect of parameters related to absorber plate and tubes on the FPLSC performance. Mukherjee et al. [49] achieved improvement in energy density and aspect ratio by using a heat storage system in a flat plate collector. An experiment is performed to see the effect of heat enhancement devices on the performance of FPLSC studied by Hobbi and Siddiqui [50]. Koholé et al. [51] performed exergy analysis on a flat plate solar collector to understand the influence of various parameters on its performance. Exergy optimization of FPLSC is done considering the parameters namely tube diameter, wind speed, ambient temperature, inlet temperature and solar irradiation studied by Farahat et al. [52]. Allowable variation in inlet fluid temperature and temperature difference between inlet and outlet temperature is evaluated with not much variation in efficiency studied by Das et al. [53]. Badran et al. [54], Gertzos et al. [55], Ogunwole [56], and Sengar et al. [57] used FPLSC as component of the system and evaluated performance of the system. A new approach Neural Network is applied to calculate the FPLSC efficiency studied by Sozen et al. [58]. Aghakhani et al. [10] studied the effect of pipe diameter and fluid flow rate on a spiral tube flat plate collector. Bello et al. [59] developed a solar oven using FPLSC and evaluated the efficiency of the system. Performance comparison of fixed FPLSC collector with tracking mechanism based FPLSC is done in Prasad et al. [60]. Heat loss coefficients are evaluated experimentally for different wind velocities studied by Bhatt et al. [61]. Nano fluid is used in FPLSC as heat carrying fluid and the performance improvement of FPLSC at different flow rates, inlet temperature, solar irradiance and ambient temperature was observed by Yousefi et al. [62]. Alawi et al. [63] exhaustively reviewed the application of various nanofluids in enhancing the performance of a flat plate collector. The use of aluminium oxide-crystal nano-cellulose studied by Farhana et al. [64], a mixture of Titanium oxide-water studied by Moravej et al. [65] and TiO_2/SiO_2-water studied by Abu-Hamdeh et al. [66] nanofluids enhanced the efficiency of flat plate solar collector. Effect of selective anti reflecting coating on the FPLSC efficiency and glass transmittance was evaluated by Ehrmann and Reike-Koch [67]. Instantaneous performance of FPLSC is evaluated considering the effects of wind velocity, collector ageing, radiation loss, irradiance incidence angle and thermal capacitance of all components studied by Rodriguez-Hindalgo et al. [68]. Optimal mass flow rate is calculated using TOMP algorithm during day time at different inlet temperature, solar irradiation for maximum exergy extraction studied by Badescu [69]. Optimal FPLSC inclination is evaluated studied by Maghadam et al. [70]. Area compensation ratio is evaluated for different roof azimuthal angle and tilt angle studied by Wei et al. [71]. Gunerhan et al. [72] evaluated the optimum tilt angle for FPLSC for building application in terms of latitude and day of the year. Ghoneim et al. [73] evaluated the effect of different arrangement of square celled honey comb material on the FPLSC efficiency. These are placed between the absorber plate and transparent cover to reduce the upward heat transfer rate. Bhargva and Yadav [74] reviewed the application of an evacuated tube collector in a solar still and its effect on the freshwater output from the still. The performance of different devices using FPLSC namely solar water heater, solar still and heat pump was evaluated in Gertzos et al. [75], Ayompe et al. [76], Panchal et al. [77], Ozsabuncuoglu [78], Georgiev [79], Hang et al. [80], Varol et al. [81], Koca et al. [82]. The performance improvement of FPLSC was also evaluated using phase changing material for energy storage. Alwan et al. [83] experimentally examined the thermal performance of a FPLSC in Russian climatic conditions. Hou et al. [84] showed a new method to measure the time constant of solar collector. Rossiter Jr et al. [85] investigated the degradation of heat transfer fluid using ion chromatography. Loutzenhiser et al. [86] validated the models that are used to calculate solar radiation on the surface. Sopian et al. [87] studied the performance of solar collector which is made of thermoplastic natural rubber. The work was also done on the materials that are used to safeguard the collector from over-heating studied by Resh and Wallner [88]. experiment was performed to analyse the uplift force acting on the solar water heater in Taiwan studied by Chung et al. [89]. Anderson et al. [90] observed the effect of absorber colour on the collector performance. Eltaweel et al. [91] performed the energy and exergy analysis to compare the thermal performances of a flat plate solar collector and an evacuated tube collector. From the above research papers 182 attributes about FPLSC are collected. The number of attributes identified will increase as the research continues in this field. The main components of a header and riser type FPLSC are shown in fig.3.

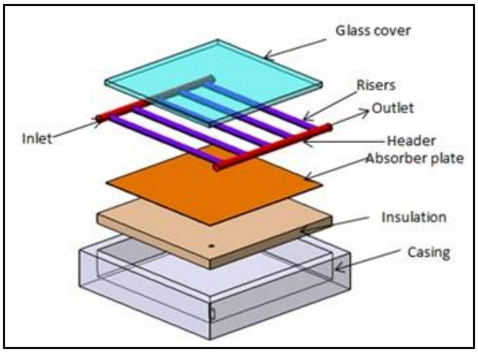


Figure 3. Components of FPLSC

Attributes are large in number and for better handling they are categorized as follows:

3.1.1 Input attributes- Attributes which are used to evaluate the performance of the FPLSC collector. These are divided further as follows:

i. General attributes- Attributes related only to the FPLSC designing such as absorber plate, transparent glass cover, 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 included in this category.

v Application based- Attributes related to the system in which FPLSC is a component of the system e.g. solar still, solar water heater, solar oven, solar cooling etc.

3.1.2. Type of work- To give information about work done by the researcher to study the system. It is further categorized as follows:

i. Simulation- Software used to simulate FPLSC performance and other factors.

ii. Theoretical - There are many theoretical approaches used to evaluate the collector. The particular type of approach is also used as an attribute.

iii. Experimental – During experimentation different instruments are used to measure system properties.

3.1.3. Output attributes- Attributes related to the output that are studied corresponding to the FPLSC and its applications.

3.2. Coding scheme and formation of IM for FPLSC

Coding of attributes is done as discussed in section 2.3. A matrix m*n is developed as discussed in section 2.4. Where m represents the number of attributes and n represents the number of papers. IM is developed for FPLSC in which 78 papers are used and 183 attributes are collected. All the papers are not shown in the matrix because of space constraints 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 different experimental works. So these attributes are not quantifiable but only put Y in the cell of corresponding paper in which these are present.

In table.5 P1 is represented by paper [29], P2 is represented by paper [30]; similarly P78 is represented by paper [11]. Information obtained from IM for FPLSC is that the performance of a FPLSC is influenced by the environmental 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 which makes it necessary to find their effect on FPLSC performance. From the IM, it is observed that ambient temperature, solar irradiation and wind velocity are the 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 the collector. Operating parameters that are identified from IM are type of fluid used, fluid inlet temperature, and flow rate, integrated to the building or separate and tilt angle. Information about different type of applications of the FPLSC like solar still, solar heat pump, solar cooling system, and effluent evaporation system, solar geyser cum distiller, solar oven, solar water heater, and solar cooker are extracted from the IM. This information is helpful in widening the area of thinking of an 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 an important parameter for optimum water production, and type of heat exchanger, amount of hot water required, and storage tank dimensions in a solar water heater. Papers related to a particular application are easily sorted out from the IM 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 a budding researcher. The main outputs that most of researchers are focused about are absorber plate temperature, useful energy collected by fluid, efficiency and outlet water temperature. A number of different approaches like 1-D and 2-D heat transfer equations, Neural Network, FDM, mathematical modelling, TOMP etc. used to evaluate the performance of flat plate collector are collected in the IM. It creates flexibility to evaluate the collector. Papers are easily collected from the matrix using 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 locate these papers. If 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 could be obtained from the IM of FPLSC. The researcher can locate the papers involving experimental investigations easily with the help of the information matrix. Many analytical results from softwares used to evaluate the FPLSC are also included 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 could be easily located from the IM. Instruments used in the experimental setup of FPLSC and its applications are also collected in IM which will be useful for the budding researchers during experimentation. The information pertaining to the design parameters affecting the performance of FPLSC are collected in the IM. This will provide the designer with a good idea about the important attributes while designing a FPLSC. As discussed in section 2.4 about the calculation of total work done on a particular attribute in a particular paper, sigma forms at the right and bottom of the IM gives this information. From the IM of FPLSC, it is observed that comparatively less amount of experimental and theoretical investigations are performed on the application of FPLSC in a vapour absorption refrigeration systems, air-conditioning and heat pump applications.

FPLSC assisted solar stills and solar water heaters are the main applications studied by many researchers. This IM is useful to find gaps in a particular research field. This information is useful to the new researcher to get to know the gaps easily for further research. A comprehensive and exhaustive cause and effect diagram is developed on the performance of FPLSC as shown in Fig. 4(a). Different causes and performance based parameters of FPLSC are shown in Fig. 4(a). Gaps could be found by comparing the information from the cause and effect diagram and IM for FPLSC simultaneously. From the cause and effect diagram, it is observed that bonding between absorber plate and tubes affect 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 understand their influence on the

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. Limited work is done to see the effect on the performance of FPLSC by varying the thickness of tube. Thickness of the tube should be kept minimum for better performance. In case thin tubes are not available in the local market and 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 the 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 and corrodes the tubes which degrades the tube performance. So it is necessary to evaluate the effect of reactivity on collector.

Table 5**.** IM for FPLSC

Sr. No.	Attributes	Paper							Sum
		P1	P2	–	P16	–	P41	P78	
	Input Attributes								
	1. General								
	1.1 Absorber Plate	N	N		N		N	N	
1	Type of Absorber	0	0		0		0	0	2
2	Absorber Shape	0	0		0		0	0	4
3	Micro Capillary Film (MCF) Void age	0	0		0		0	0	2
4	Absorber Area	0	0		0		0	0	4
5	Absorber Material	0	0		0		0	0	1
6	Absorber Emissivity	0	0		0		0	0	4
7	Thermal Conductivity of Absorber	0	0		0		0	0	2
8	Selective Coating of Absorber	0	0		0		0	0	4
9	Absorber Color	0	0		0		0	0	4
	1.2 Tubes	Y	Y		Y		N	N	-
10	Heat Enhancement Devices	0	0		3		0	0	3
11	Length of Tubes	0	1		0		0	0	4
12	Number of Tubes	0	2		0		0	0	5
13	Diameter of Riser	2	0		0		0	0	4
14	Spacing B/W Risers	2	2		0		0	0	6
	1.3 Transparent Cover	Y	N		N		N	N	-
15	Cover Material	0	0		0		0	0	2
16	Absorptivity of Cover	0	0		0		0	0	4
17	Selective Coating of Cover	0	0		0		0	0	4
18	Transmittance of Cover	0	0		0		0	0	3
19	Number of Covers	3	0		0		0	0	8
20	Optical Efficiency	0	0		0		0	0	2
21	Reflectance of Cover	0	0		0		0	0	3
22	Cover thickness	0	0		0		0	0	-
	3. Operational	Y	Y		Y		N	N	-
23	Tilt	0	0		0		0	0	18
24	Flow Rate	3	0		3		0	0	33
25	Fluid Inlet Temp.	4	4		0		0	0	35
26	Fix To Wall	0	0		0		0	0	3
	4. Environment	N	N		Y		N	Y	-
27	Solar Irradiation	0	0		3		0	3	68
28	Wind Velocity	0	0		0		0	0	18
29	Ambient Temp.	0	0		0		0	0	35
	2 Others	N	N		N		Y	Y	-
30	Type Of Fluid	0	0		0		0	0	7
31	Fluid Concentration	0	0		0		0	0	4
32	Specific Heat Of Fluid	0	0		0		0	0	1
33	Phase Changing Material	0	0		0		2	2	4
34	Tracking	0	0		0		0	0	7
35	Type Of Conditions B/W Absorber Plate & Glass Cover (Vacuum)	0	0		0		0	0	3
36	Different Arrangements Of Honey Comb Materials	0	0		0		0	0	2

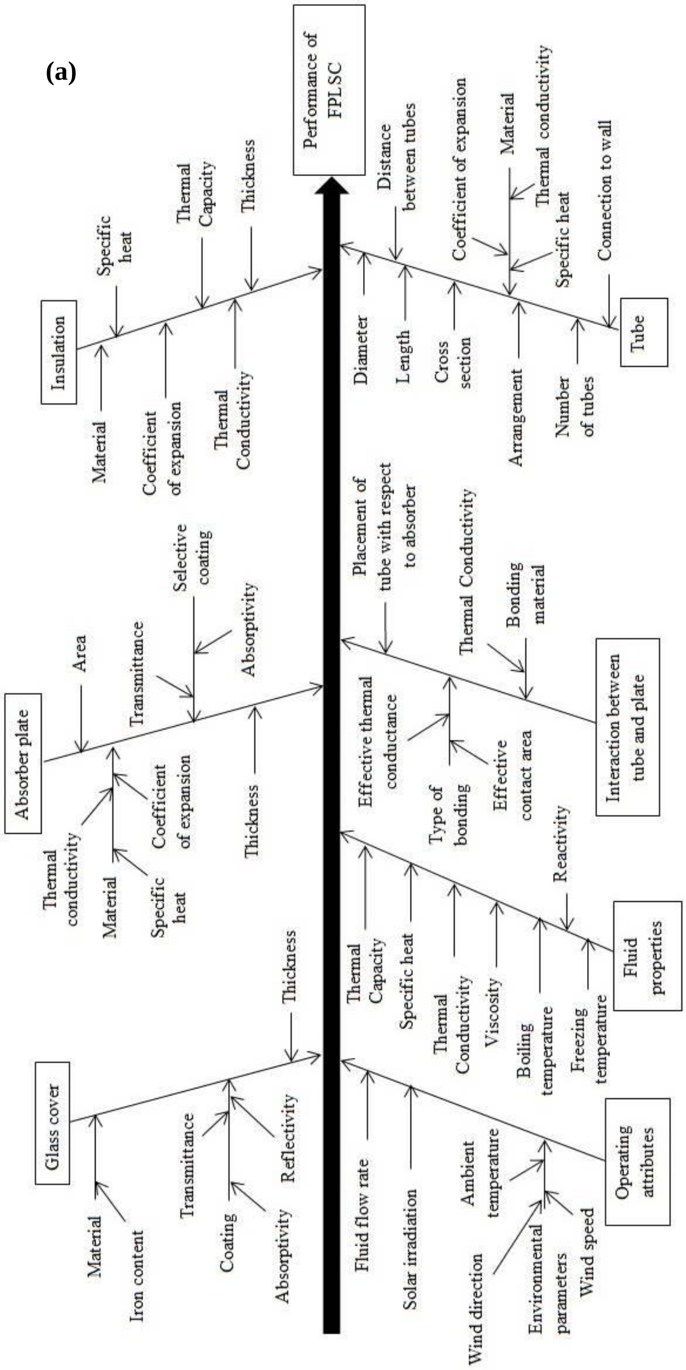
37	Distance B/W Absorber Plate & Honey Comb Material	0	0		0		0	0	3
38	Distance B/W Transparent Cover & Honey Comb Material	0	0		0		0	0	3
39	Insulation Material	0	0		0		0	0	2
40	Thermal Capacitance Of All Components	0	0		0		0	0	3
41	Collector Aging	0	0		0		0	0	3
42	Hour Angle	0	0		0		0	0	4
43	Declination Angle	0	0		0		0	0	6
44	Latitude	0	0		0		0	0	7
45	Roof Azimuthal Angle	0	0		0		0	0	4
46	Roof Tilt Angle	0	0		0		0	0	4
47	Location	0	0		0		0	0	4
48	Efficiency	0	0		0		0	0	2
49	Wind Heat Transfer Coefficient	0	0		0		0	0	3
50	Absorber Plate Temperature	0	0		0		0	0	5
51	Azimuthal Angle	0	0		0		0	0	2
52	Incidence Angle	0	0		0		0	0	4
53	Radiation Loss	0	0		0		0	0	3
54	Date	0	0		0		0	0	2
55	Time	0	0		0		0	3	5
56	Deviation In Inlet Fluid Temperature								-
	5. Application	N	N		N		Y	Y	-
	5.1 Effluent Evaporation System	N	N		N		N	N	-
57	Concentration Of Effluent	0	0		0		0	0	4
58	Relative Humidity	0	0		0				4
	5.2 Solar Still	N	N		N		N	N	-
59	Water Depth	0	0		0		0	0	7
60	Direction	0	0		0		0	0	4
61	Type Of Water	0	0		0		0	0	2
62	Operating Mode	0	0		0		0	0	3
	5.3 Solar Water Heater	N	N		N		Y	Y	-
63	Type Of Auxiliary Heater	0	0		0		0	0	4
	5.3.1 Separate	N	N		N		N	N	-
	5.3.1.1 Indirect Type	N	N		N		N	N	-
	Application	N	N		N		N	N	-
64	Material Cost	0	0		0		0	0	3
65	Operation & Maintenance Cost	0	0		0		0	0	4
66	Others Cost	0	0		0		0	0	2
67	Interest Rate	0	0		0		0	0	3
68	Inflation Rate	0	0		0		0	0	2
	5.3.2 Integrated	N	N		N		N	Y	-
	5.3.2.1 Indirect Type	N	N		N		N	Y	-
69	Recirculation Rate	0	0		0		0	0	3
70	Heat Exchanger Tube Diameter	0	0		0		0	0	3
71	Distance From Tank Walls	0	0		0		0	0	4
72	Length Of Heat Exchanger	0	0		0		0	0	3
	5.4 Solar Cooker	N	N		N		N	N	-
	5.5 Solar Geyser Cum Distiller	N	N		N		N	N	-
	5.6 Solar Oven	N	N		N		N	N	-
	5.7 Heat Pump	N	N		N		N	N	-
73	Condenser Temp.	0	0		0		0	0	2
74	Medium Fluid Evaporator Temp.	0	0		0		0	0	2
	5.8 Solar Cooling System	N	N		N		N	N	-
	5.9 Water Heater + Space Heating	N	N		N		N	N	-
	6. Theoretical	Y	Y		N		Y	N	-
75	Energetic Prospective	N	N		N		N	N	3
76	Economic Prospective	N	N		N		N	N	12
77	Environment Prospective	N	N		N		N	N	25
78	Sensitivity Analysis (Regression Analysis)	N	N		N		N	N	2
79	FVM	N	N		N		N	N	5
80	Evaluate The Effect Of Glass	N	N		N		N	N	7

	Absorptivity On The System Performance								
81	One Dimension Heat Eqn.	N	N		N		N	N	3
82	Two Dimension Heat Eqn.	N	N		N		N	N	2
83	Two Dimensional Finite Element Model	Y	N		N		N	N	2
84	Neural Network	N	N		N		Y	N	1
85	Adaptive-Network-Based Fuzzy Inference System (ANFIS)	N	N		N		Y	N	1
86	Support Vector Machines (SVM)	N	N		N		Y	N	1
87	Mathematical Model	N	N		N		N	N	5
88	Exergy Analysis	N	N		N		N	N	15
89	Temp	N	N		N		N	N	14
90	TOMP	N	N		N		N	N	1
91	FDM	N	N		N		N	N	3
	7.Experimental	N	N		Y		Y	Y	-
	8. Simulation	N	N		N		N	N	-
92	CFD	N	N		N		N	N	5
93	TRNSYS	N	N		N		N	N	4
94	TRNFLOW	N	N		N		N	N	2
95	MATLAB	N	N		N		N	N	6
96	MINSUN	N	N		N		N	N	1
97	WATSUN	N	N		N		N	N	1
98	Kolektor 2.2	N	N		N		N	N	2
99	ANSYS	N	N		N		N	N	2
	9. Instruments	N	N		Y		N	N	-
100	Thermocouple	N	N		Y		N	N	65
101	Millivoltmeter	N	N		N		N	N	5
102	Pyranometer	N	N		N		N	N	70
103	Solar Cell	N	N		N		N	N	1
104	Piezometer Tube	N	N		N		N	N	2
105	Mercury In Glass Thermometer	N	N		N		N	N	1
106	Wet & Dry Bulb Thermometer	N	N		N		N	N	2
107	Digital Anemometer	N	N		N		N	N	17
108	Kipp-Zonen Solarimeter	N	N		N		N	N	23
109	Surya Mapi	N	N		N		N	N	5
110	Buoyancy Meter	N	N		N		N	N	3
111	Insolometer	N	N		N		N	N	6
112	Pid Controller	N	N		Y		N	N	1
113	Rotameter	N	N		Y		N	N	4
114	PROVA (Av M-07)	N	N		N		N	N	1
115	Tes1333r Solar Meter	N	N		N		N	N	1
	Output Variables								-
	1 General								-
116	Bottom Heat Loss	N	N		N		N	N	10
117	Absorber Plate Mean Temperature	N	N		N		N	N	8
118	Top Heat Loss	N	N		N		N	N	4
119	Top Loss Coefficient	N	N		N		N	N	8
120	Efficiency	Y	Y		N		Y	N	65
121	Nusslet No.	N	N		N		N	N	25
122	Rayleigh No.	N	N		N		N	N	21
123	Glass Temperature	N	N		N		N	N	71
124	Side Heat Loss	N	N		N		N	N	19
125	Edge Heat Loss	N	N		N		N	N	8
126	Fluid Temperature Variation Along The Tube	N	N		N		N	N	7
127	Fluid Outlet And Inlet Temperature Difference	N	N		Y		N	N	9
128	Pressure Drop	N	N		N		N	N	5
129	Absorber Mean And Ambient Temp. Difference	N	N		N		N	N	11
130	Thermal Performance	N	N		Y		N	N	34
131	Useful Energy	N	N		N		Y	N	16
132	Fluid Outlet Temperature	Y	N		N		N	N	50
133	Radiation Loss	N	N		N		N	N	12
134	Exergetic Efficiency	N	N		N		N	N	13
135	Tolerable Fluid Inlet Temperature Variation	N	N		N		N	N	2
136	Tolerable Variation In Temperature Difference Of Outlet And	N	N		N		N	N	1

	Inlet Temperature								
137	Insulation Temperature	N	N		N		N	N	3
138	Compare The Results Of Two Dimension And One Dimension Model	N	N		N		N	N	2
139	Tilt	N	N		N		N	N	11
140	Collector Area Ratio	N	N		N		N	N	6
141	Auxiliary Energy	N	N		N		N	N	3
142	1st Glass Cover Inner Temp.	N	N		N		N	N	3
143	1st Glass Cover Outer Temp.	N	N		N		N	N	3
144	2^{nd} Glass Cover Inner Temp.	N	N		N		N	N	4
145	Top Face Convective Heat Transfer Coefficient	N	N		N		N	N	5
146	Top Face Radiative Heat Transfer Coefficient	N	N		N		N	N	2
147	2^{nd} Glass Cover Outer Temp.	N	N		N		N	N	4
148	Cost	N	N		N		N	N	12
	2 Application								-
	2.1 Solar Still								-
149	Amount Of Water Produced In Still	N	N		N		N	N	72
150	Condensate Temperature In Still	N	N		N		N	N	7
151	Glass Inside Temperature	N	N		N		N	N	19
152	Water Temperature In Still	N	N		N		N	N	67
153	Vapor Temp. Produced In Still	N	N		N		N	N	21
154	Glass Outside Temperature	N	N		N		N	N	65
	2.2 Solar Water Heater								-
155	Solar Fraction	N	N		N		N	N	2
156	Energetic And Environmental Payback Periods	N	N		N		N	N	2
	2.2.1 Separate								-
	2.2.1.1 Indirect Type								-
157	Service Water Outlet Temperature	N	N		N		N	N	2
158	Production Cost At Manufacturer Level	N	N		N		N	N	2
159	Initial Cost At User Level	N	N		N		N	N	6
160	Total Cost	N	N		N		N	N	15
161	Cost Comparison	N	N		N		N	N	15
162	Cost Saving	N	N		N		N	N	7
	2.2.2 Integrated Heat Exchanger								-
	2.2.2.1 Indirect Type								-
163	Useful Energy	N	N		N		N	Y	9
164	Exergy Efficiency	N	N		N		N	Y	9
165	Flow Path In The Tank	N	N		N		N	N	2
166	Velocity Distribution In The Tank	N	N		N		N	N	3
167	Temperature Of Tank	N	N		N		N	N	4
168	Service Water Outlet Temperature	N	N		N		N	N	2
169	Service Water Flow Rate	N	N		N		N	N	3
170	Storage Volume	N	N		N		N	N	2
171	Performance	N	N		N		N	N	11
172	Auxiliary Energy	N	N		N		N	N	2
	2.3 Effluent Evaporation System								-
173	Evaporation Rate	N	N		N		N	N	3
	2.4 Solar Cooker								-
174	Absorber Temperature	N	N		N		N	N	23
	2.5 Heat Pump								-
175	Cop	N	N		N		N	N	4
176	Efficiency	N	N		N		N	N	3
	2.6 Solar Geyser Cum Distiller								-
177	Storage Temperature	N	N		N		N	N	2
178	Amount Of Water Produced	N	N		N		N	N	45

	2.7 Water Heater + Space Heating								-
179	Solar Fraction	N	N		N		N	N	5
	2.8 Solar Oven								-
180	Efficiency	N	N		N		N	N	7
	2.8 Solar Cooling						-	-	-
181	COP	N	N		N		N	N	3
182	Efficiency	N	N		N		N	N	13
	Sum	14	9		9		2	8	-

(a)



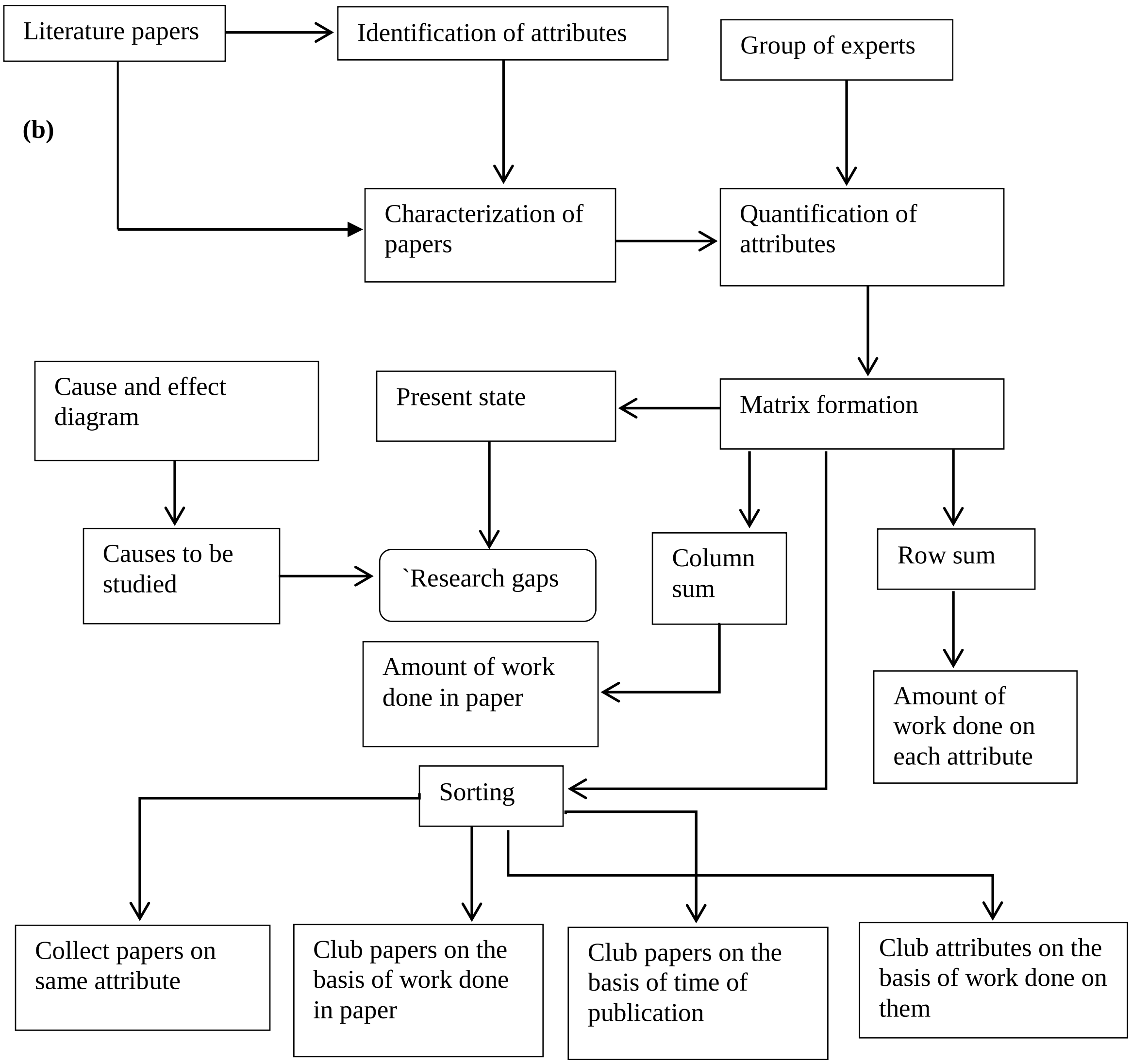


Figure 4. a) Cause and effect diagram for the performance of FPLSC; b) Flowchart of methodology

4. Step by step procedure

The flow chat of the methodology adopted in this study is mentioned in fig. 4(b). The research papers of a particular domain are collected and the attributes are identified as per research interest of the user. An information matrix between the research papers and attributes is developed along with the cause and effect diagram to understand the effect of attributes efficiently.

5. Conclusion

In this study, an exhaustive database is formed using information from the existing data present in research papers. The different attributes affecting the performance of FPLSC are identified and given codes on the basis of their utility. An information matrix is developed to estimate the research work done on a particular attribute which helped in identifying the research gaps efficiently. The information matrix also facilitates the sorting of research papers concerning particular attributes and extraction of relevant information. A spider graph is also drawn which is a helpful in getting suitable research paper of interest on the basis of attributes. This attribute based literature review has a provision of updation of data as the research associated with flat plate solar collector advances making it an informative database and beneficial for the readers. The future scope of this study includes the updation of data in the information matrix related to the thermal performance parameters, design and operating parameters of the FPLSC. The research data from recent advancements in the FPLSC system design, applications, integration with other thermal systems and related economics could be added to the present database.

Nomenclature

FPLSC	Flat plate liquid solar collector
IM	Information matrix
NTU	Number of transfer units
P	Research paper
A	Attribute
ε	Effectiveness

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