Journal of Information Systems Engineering and Management

2025, 10(28s)

e-ISSN: 2468-4376

https://www.jisem-journal.com/

Research Article

Linear and Annular Fresnel Collectors: Recent Developments and Performance Optimization

Balqis Ali Saleh[1*], Qusay Jihad Abdul Ghafoor[2]

[1]Department of Ministry of Industrial and Minerals, 10011, Baghdad, Iraq.

[2]Department of Mechanical Engineering, University of Technology, 10011, Baghdad, Iraq.

[*]Corresponding author email: me.22.11@grad.uotechnology.edu.iq

ARTICLE INFO

Received: 21 Dec 2024

Revised: 20 Feb 2025

Accepted:26 Feb 2025

ABSTRACT

The increasing demand for sustainable energy solutions has driven significant advancements in solar energy harvesting technologies. Among these, Fresnel lens-based solar collectors have emerged as a promising approach for enhancing efficiency and cost-effectiveness in solar thermal applications. This review provides a comprehensive analysis of the latest research on Fresnel lens technology, focusing on its application in linear Fresnel collectors (LFC), solar tracking systems, and annular Fresnel collectors (AFC). Innovations in optical design, thermal efficiency, and hybrid applications (e.g., cogeneration, desalination) are analyzed, highlighting performance improvements and industrial viability. The review also highlights key experimental and theoretical studies that have contributed to the advancement of Fresnel lens-based solar systems. Key experimental and theoretical studies demonstrate that optimized Fresnel configurations and tracking mechanisms enhance energy output by 15–30%, balancing cost and land-use efficiency. The findings suggest that continuous improvements in Fresnel lens configurations and integration with tracking mechanisms have significantly improved their overall efficiency, making them viable solutions for large-scale solar energy applications.

Keywords: experimental, mechanisms, demonstrate, improvements

1. INTRODUCTION

Solar energy is a cost-effective and ecologically friendly solution that effectively fulfills various human energy needs [1]. Solar thermal collectors are devices that capture solar energy and convert it into usable heat. Evacuated tube collectors and flat plate collectors are the preferred options for low-temperature applications, typically about 100 °C [2]. Concentrated solar collectors are often preferred for temperature ranges between 100 and 300 °C [3]. For elevated temperatures, parabolic trough collectors (PTC) and linear Fresnel collectors (LFC) are the preferred options [4].

LFCs have been extensively researched and evaluated for solar applications. They are regarded as among the best favorable instruments for solar power collecting, owing to their comparatively affordable simplicity and cost. The groundbreaking research conducted by Francia [5] initiated global interest in the concept of LFC. Initially, this interest was sporadic, encompassing complete practical reports [6], studies on geometry design [7–10], prototype investigations [13], and analyses of receivers [11,12]. However, in the modern era, interest surged in introducing the geometry Compact LFC [14], leading to comprehensive analyses and additional configuration proposals [15–20].

As in Figure 1 [21], for LFC, a solar array consisting of sleek mirror panels, each pivoting near a ground-level horizontal axis, follows the sun and directs the mirrored radiation to a stationary advanced receiver. This receiver typically functions as a thermal absorber, heating the fluid of the heat transfer to provide a power block; however, it may alternatively serve as a hybrid PV/T absorber or an appropriately cooled narrow PV strip.

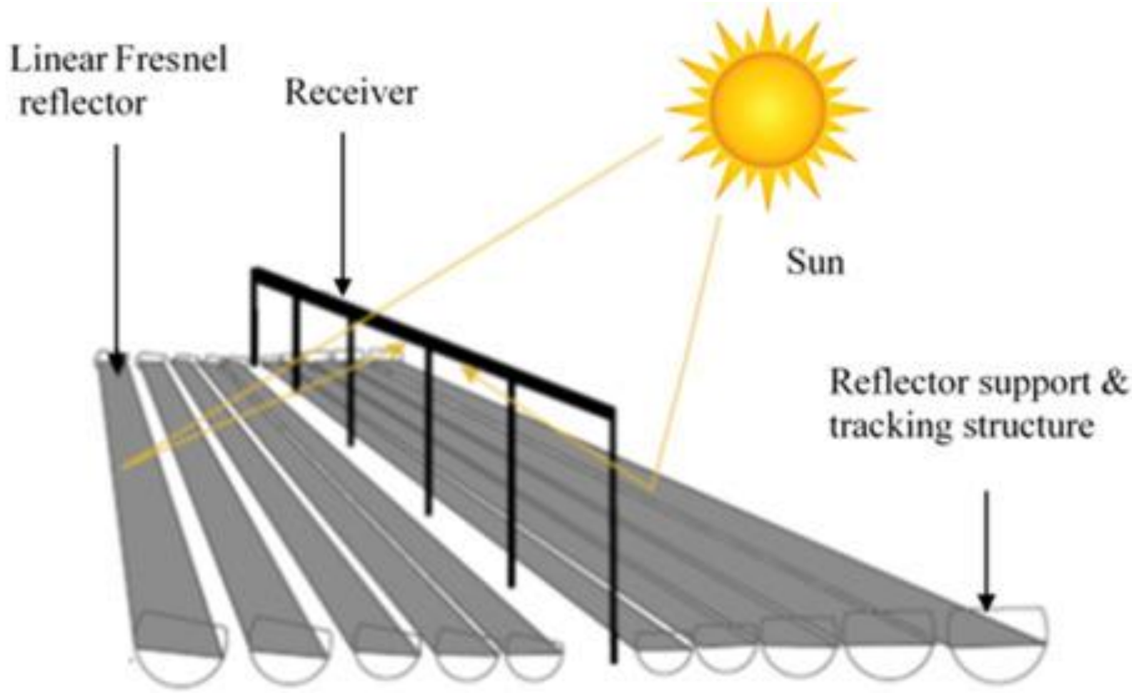


Figure 1: Linear Fresnel collector [21]

The distinction between LFR and parabolic troughs demonstrated that PTC exhibits significantly greater optical efficiency, resulting in enhanced energy generation. The reduction in overall efficiency is estimated to be between 23–40% for a single tube receiver, as indicated in [22], with the deviation being caused by the receiver thermal efficiency (as this may be evacuated or not), as mentioned in Ref. [23], a smaller deviation of approximately 20% is reported. A lessening of between 32% and 23% is provided in Ref. [24]. A drop ranging from 15% to 30% is provided in Ref. [25], contingent upon the site and working environment. Generally, an LFR system that has the same total area as the collector as a PTC will have an efficiency loss of about 20-30% of the energy that would otherwise be obtained. However, this loss needs to be balanced against the significant reduction in land occupation, the advantages of a static receiver (particularly for applications with high temperatures), and the reduction in movement system complexity (short, large-curved collectors vs. nearly flat mirror strips). Cost calculations indicate that the detailed expense of a mirror of the LFR area is marginally greater than fifty percent of the cost of a PTC (52%, as stated by [22]). Most applications necessitate moderate temperature levels, and the LFC has been recognized as the most appropriate solar collector [26].

Nonetheless, the fact that garnered the most extensive attention is likely system optics. The optical efficiency under real-world conditions is essential for evaluating the energy yield achievable from a linear Fresnel reflector, which might vary significantly based on the design and characteristics of the plant. The investigation of optical characteristics has garnered significant interest from scientists in the solar energy sector. Literature includes ray-tracing analyses [27], as seen in [28–30], as well as methods that depend on analytical analysis with varying approximation degrees [31–33]; hypothetical design concepts have been suggested [34,35]; blocking and shading impacts have been examined in detail [36–38]. Additional specific analyses include the complete concentration processes for several purposes [39], a relationship between parabolic mirrors and cylindrical [40], an examination of the curvature of the mirror [41], the analysis of flow allocation on the object [42], targeting strategies [43], elevated-Zenith assessments [44], end loss calculations [45], evaluations of main mirrors [46], analyses of specific optical designs [48–51], and the spacing gap between mirrors [47]. The Modifier of Incidence Angle, which is contingent upon two incidence angles for LFCs, was examined in references [52–54].

Fresnel lenses represent a significant improvement over older methods of solar energy collecting and represent an abrupt shift in the field. Solar collectors can achieve even greater temperatures with the use of Fresnel lenses, which focus sunlight into a narrow region. Solar collectors that use Fresnel lens technology have many advantages. By facilitating the concentration of sunlight and its subsequent energy capture, these lenses allow for the development of more efficient and cost-effective designs. For numerous uses, including industrial processes and home heating, solar collectors become a more powerful and long-lasting heat source when heated to higher temperatures, which boosts their overall efficiency [55]. This review explores the evolution of Fresnel lens-integrated solar collectors, emphasizing LFCs, Annular Fresnel Collectors (AFCs), and tracking systems. The objective is to synthesize recent advancements, assess performance metrics, and identify future research opportunities.

2. LINEAR FRESNEL COLLECTOR

LFCs utilize linear Fresnel lenses or reflectors to concentrate sunlight onto a fixed receiver, making them ideal for medium-temperature applications. Recent studies highlight significant progress in optical design, thermal efficiency, and scalability.

2.1 Optical and Thermal Efficiency Enhancements

In 2014, Jang et al. [56] introduced a novel system for medium-CPV lenses that produce linear-type Fresnel patterns with the aim of effectively and consistently lighting 10 x 10 mm^2 silicon solar cells. Scientists attained optical efficiency ranging from 85 to 87% by optimizing the lighting object instruments in Light Tools. Achieving realistic optical efficiency in lenses is a key step in developing CPV modules. In 2017, Perini et al. [57] presented a model for a novel LFC that can be tracked in two dimensions. Finding the performance curve of this technology was the major objective of the experimental and theoretical analyses. The theoretical model included the heat transfer model of the receiver pipe and the concentrator optical model. Experimental data obtained utilizing a prototype situated in the UK validated the efficiency of this instrument. The efficiency of the collector was tested in conditions ranging from 40 to 90 ^oC. The research showed that the collector has a maximum overall efficiency limit of 20%. Optical losses in the lens system were responsible for 47% of the overall energy loss. A trifecta of absorption, reflection, and diffraction was employed by Fresnel lenses to produce these effects. Because the temperatures that were present were modest, up to 90 ^oC, convention and thermal radiation only accounted for 6% of the total. In 2019, Kaddoura and Zeaiter [58] used a mathematical model to examine the annual energy storage and thermal behavior of a solar cavity receiver with Fresnel lenses, aiming to determine the best design for the receiver. By simulating fluid flow and radiation transport using computational fluid dynamics (CFD), They were able to learn more about the heat transfer mechanisms inside the enhanced form. Outdoors, with 4 distinct solar irradiation levels (500-1000 W/m^2) and 8 distinct heat transfer fluid (HTF) flow rates, the experimental results of the simulation were examined (Figure 2). Predictions about the receiver's thermal efficiency, the HTF's output temperature, and the quantity of stored energy for each month of the year were all made with the use of this model. A study found that the laboratory-scale Fresnel lens can raise the HTF's temperature by 200 °C. It is expected that the amount of thermal energy stored would range between 2 and 7.2 kWh/m^2 daily during the winter and summer months, respectively, and thermal efficiency between 93.6% and 97.2%.

In 2023, considering different incidence angles, Wang [59] investigated the efficacy of a system consisting of a Fresnel lens solar concentrator with a fixed focus and a with and without a glass cover attached to a conical cavity receiver. To achieve optimal performance, he used TracePro® 7.0 to build the system's optical models. The system's thermal performance was subsequently evaluated through an experimental setup. The results showed that the two separate systems without or with the glass cover had significantly higher optical efficiencies. The distance between them remains constant at incidence angles ranging from zero to twenty degrees. With a glass cover, the system's time constants range from 29 to 33 s, but without it, they range from 48 to 59 s, which is a very noticeable difference. Across a broader temperature spectrum, the glass-protected system exhibits better thermal efficiency.

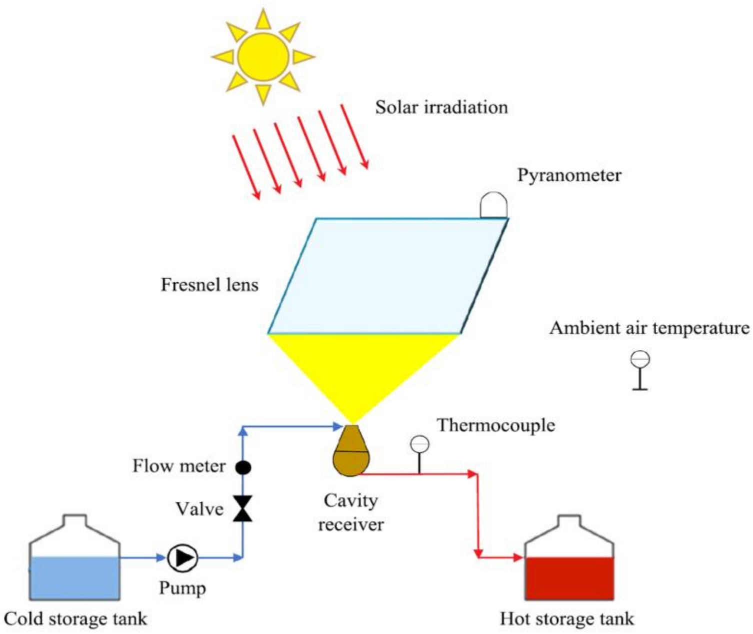


Figure 2 Experimental test-rig diagram of Kaddoura and Zeaiter [58].

2.2 Cogeneration and Hybrid Systems

In 2019, a cogeneration system that uses LFC as its power source was the main focus of Bellos et al. [60]. Figure 3 shows their system in action. The organic Rankine cycle and the lithium-bromide/water single-effect absorption chiller supplied the power and cooling in their suggested system. Under steady-state circumstances, they conducted a parametric investigation of this system using EES software. Additionally, they optimized the model for the dynamic scenario. A thermo-economic analysis was used to determine an exergy efficiency of 8.3% and an energy efficiency of 17.5%. The system's annual production was 18 MWh.

Regarding the net present value, the optimal design was a collecting area of 140 m^2, a storage tank of 1.4 m^3, and the use of toluene in an organic Rankine cycle operating at a saturation temperature of 290 °C. In 2020, an underused area in the Chinese solar greenhouse was converted into a concentrated cylindrical Fresnel PV/thermal (CPV/T) system by Wu et al. [61]. The system was engineered to guarantee that sunlight consistently strikes the lens at the correct angle. Fresnel lenses did not obstruct the plants' photosynthetically active radiation; they merely blocked part of the direct sunlight from the northern surface of the greenhouse. They utilized 18.2% of the available space for non-planting purposes. Optical modeling demonstrated that the acceptance rate remained unaffected when the incidence axial angle was maintained within 10 degrees. According to the results of the tests, the power production efficiency peaked from 11:00 to 13:00 under clear-sky conditions at around 18%, while the thermal and power generation efficiency peaked at about 55%.

In order to heat the feedwater flowing into the solar still system, Abdelsalam et al. [62] proposed and experimentally tested a method to increase the amount of solar radiation that falls on the top glass surface of the still in 2014. The purpose of this was to maximize the quantity of energy collected from the sun. According to the results of the experiment, a solar still's efficiency increased by about 68.76% compared to a standard non-concentrating solar still, and the amount of distilled water produced was almost tripled. Linear Fresnel lenses also increased solar still productivity by a factor of three or four. By combining a photovoltaic energy collector with an LFC, in 2018, an active solar distiller was created by Palomino-Resendiz et al. [63]. An autonomous robotic system guides the device and follows the sun's path to maximize water distillation and energy harvesting. Optimization of the design was done by analyzing structural, optical, thermal, and dynamic models. An effective and energy-independent alternative distillation process was achieved when the system was validated for both energy collection and water purity. Solar concentrators fitted with Fresnel lenses enable the most efficient utilization of solar light. For usage in refugee camps or other emergency situations, such as those that may develop after natural disasters, Sansom et al. [64] outlined building a small thermal desalination system in 2018. In order to maximize efficiency, condensation processes and heat evaporation were disconnected. In MENA regions with DNI > 700 W/m^2 for 8 hours, the design was predicted to produce 100 L of fresh water daily, assuming an efficiency of 50%. Figure 4 shows the desalination prototype of Version V2.

Utilizing sun radiation, Gang et al. [65] created a solar-powered multi-eccentric tube desalination system in 2019. The interior side of the tube is lined with an absorbent substance that allows it to take focused solar energy and transfer it to a film of falling water. Heating the system to 400 to 1600 W temperatures was one of the conditions examined. For the purpose of recouping heat loss, the desalination equipment was built with a conductive two-layer case. At 1600 W of heating power, the investigation indicated that the first effect's highest cumulative yield was around 28.27 kg, and at full capacity, the PR reached 1.41 and 1.07 kg, respectively. Results from 24-hour outdoor trials indicated a peak performance ratio of 2.88 and a total output of 11.35 kilograms. The research recommends a 63.68 kg/d linear Fresnel reflector desalination system that uses two-effect tubular filters.

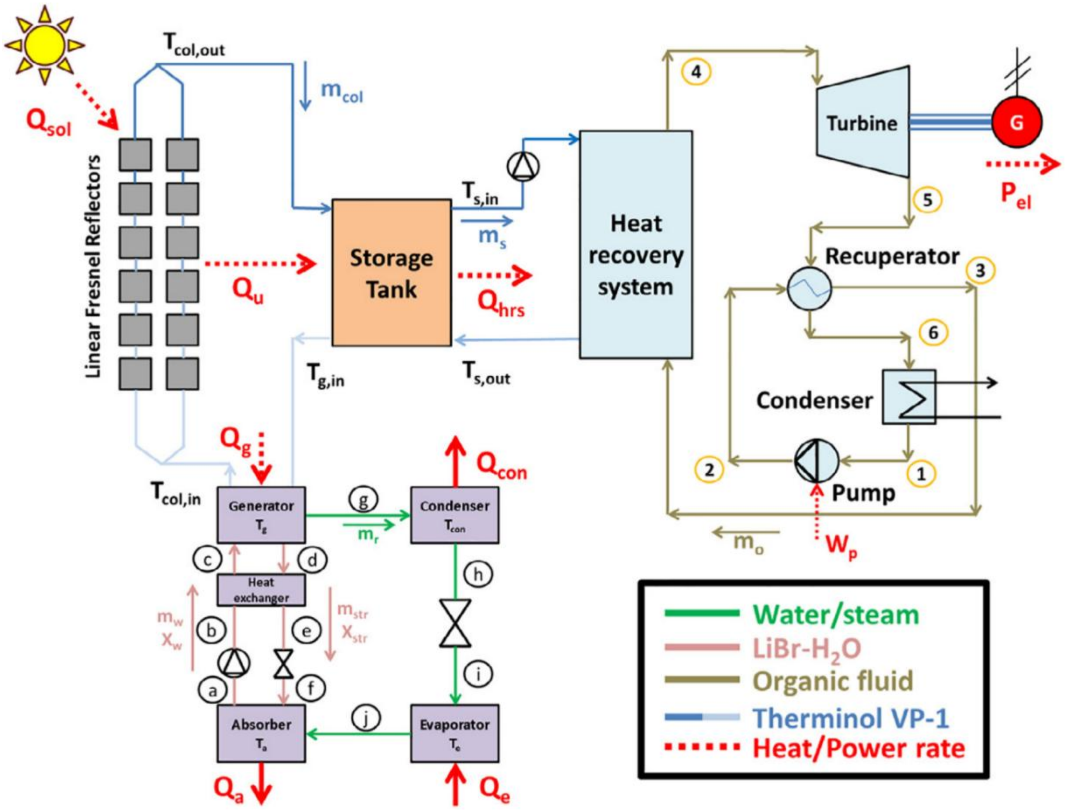


Figure 3 Proposed schematic of an LFR-equipped cogeneration system by Bellos et al. [60].

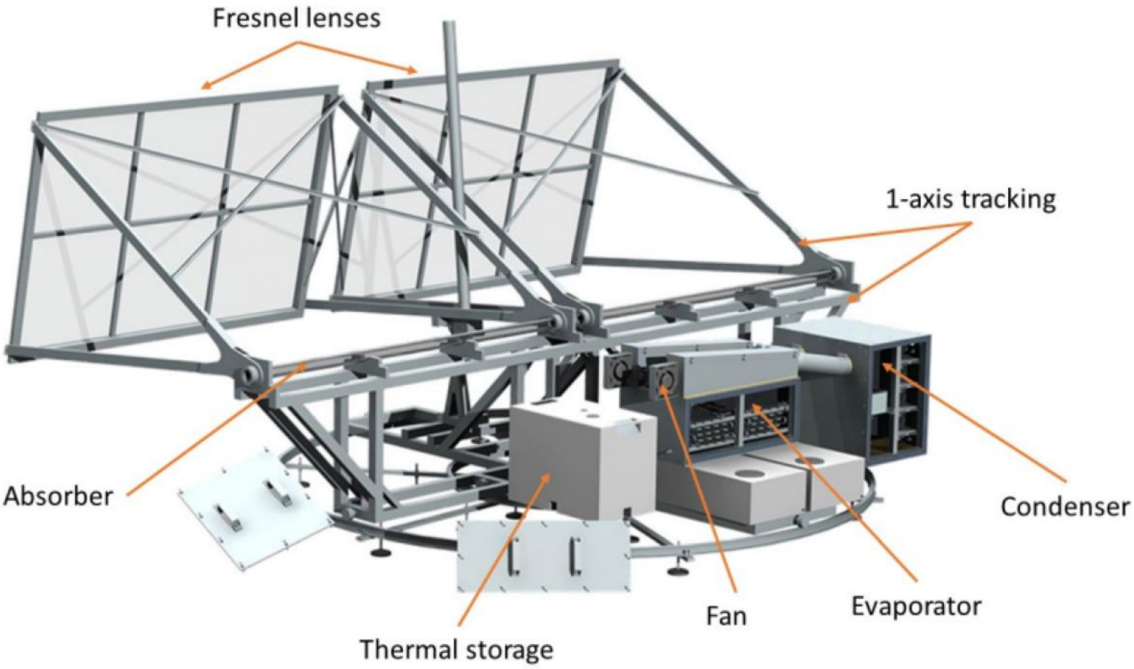


Figure 4 Sansom et al. [64] *desalination prototype Version V2.*

2.3 *Design Innovations*

In 2020, a zoomable Fresnel lens (ZFL) using tensile deformation was proposed by Ma et al. [66] to address the problem of a decreased focal length caused by tilted sun incidence. The ZFL sample, with dimensions of 240 mm focal length and 95 mm width, was created and assessed. The results showed that a 30% rise in the width of the ZFL would outcome in a 75% spread in the focal length, as mentioned in Figure 5. Whether the angle of inclination of incidence is between 0° and 40° during zooming, the focus can remain on the designated focal plane. Under normal incidence, the lowest interception coefficient for a receiver with a 10 mm wide and 20 mm length was 85%. The outcomes asserted that after the tilt incidence angle reached 25°, the ZFL should have started to stretch. Twenty millimeters of elongation is 2.5 times greater than the ZFL in its undistorted form, and it can withstand a tilt incidence angle of about 50 degrees.

Furthermore, by extending the ZFL's illumination area, the stretching procedure can potentially cover the energy loss due to distortion. With ZFL, the allowed tilt incident angle is typically increased by about 2.5 times, giving the LFC about 6.7 hours of active daily operating time. In 2020, Ma et al. [67] presented a groundbreaking design that streamlines refractions on prisms, allowing for the best Fresnel lens form to be obtained. To keep things simple, they used one refraction on the top surface. Differential equations characterized the standard structure of the Fresnel lens. A set of confocal curves was shown to be the only solution to the differential equation. At total refracted angles below 30^o, the basic circle could be used as the Fresnel lens profile. Next, after meticulous preparation, a Fresnel lens was made. The change in focal length during tilt incidence was mostly studied through experimental and modeling approaches. An improved effective tilt incidence angle ranging from 7^o to 32^o can be achieved by elevating the receiver's attitude and adding a mirror minor reflector. The tests showed that the best time to use the LFC is between 10:00 a.m. and 1:00 p.m. Presented in Figure 6 are the collection efficiencies at steady output temperatures of 125 ^oC, 150 ^oC, and 170 ^oC, which were around 53%, 48%, and 44%, respectively.

In 2021, a Fresnel-type solar prototype was optically optimized by Beltagy [68], as shown in Figure 7. The influence of the shape and the glass of the receiver on performance was evaluated through parametric studies and sizing calculations, and the system was optimized accordingly. The authors found the optimal configuration for the solar prototype by analyzing data presented in the form of curves and tables. This configuration enhanced both the theoretical and experimental outcomes. This optimal design has been the basis for the development and sale of multiple LFC-based thermal power plants.

Additionally, a number of computational models have been verified using reliable and high-tech measuring instruments. The outcomes revealed that eliminating glass could achieve a gain in optical efficiency of 5.6% annually. The annual optical efficiency increased by 15.5%, which was achieved by adding two absorber tubes instead of one. In 2022, using an arrangement of 2 large Fresnel lenses and 6 segmented mirrors, Gupta et al. [69] proposed and experimentally demonstrated the use of concentrating sunlight inside a shared space, eliminating the necessity for mechanically tracking the sun. Water was heated efficiently utilizing solar thermal power with the help of the proposed technology. Two lenses were angled so they were straight ahead of the sun so that the maximum amount of sunlight could be collected in the morning, lunchtime, and evening. In addition, the receiver unit was left in direct sunlight all day long because the distance between it and the Fresnel lenses was tall enough to avoid shadowing. The solar thermal system's efficiency was greatly improved by the concentrated sunlight during the day. This is because both concentrated and direct sunlight was directed onto the solar thermal receiver using the proposed technique. A thermal receiver apparatus was set up in the common area to heat the fluid there rapidly. They tested the proposed receiver unit concentrating system, designed the setup in ZEMAX, and analyzed the direct and accumulated solar irradiation laboratory data. Their thermal performance was evaluated against that of a segmented mirror system and one large Fresnel lens. The instantaneous thermal efficiency was up to 20% greater than that of a basic focusing lens.

In their 2022 study, Jensen et al. [70] examined the first field of large-scale Fresnel lens solar collectors. A total of 144 dual axis tracking solar collectors supplied power to the network of the district heating in Lendemarke, Denmark. In a quasi-dynamic test configuration, the thermal efficiency of the collector's solar field was measured. It was discovered that semi-losses of the total heat in the field of solar power came from the collectors, and their maximum efficiency was 11% less than with a new collector. One year of external utilization without maintenance of the collectors led to soiling, which in turn reduced peak efficiency.

Furthermore, a TRNSYS computational model was used to determine the annual performance system, which was then validated using measurement data. With input and output temperatures of 50 °C and 90 °C, the heat creation in 2020 was 373 kWh/m^2 (compared to the space area). Changes to the soiling level, mean collector temperature, and ground cover ratio were also examined for their impact on annual heat output. The sensitivity analysis showed that, unlike flat-plate collectors, the collectors' capacity to produce heat at and above one hundred degrees Celsius was little influenced by changes in the average temperature of the collector.

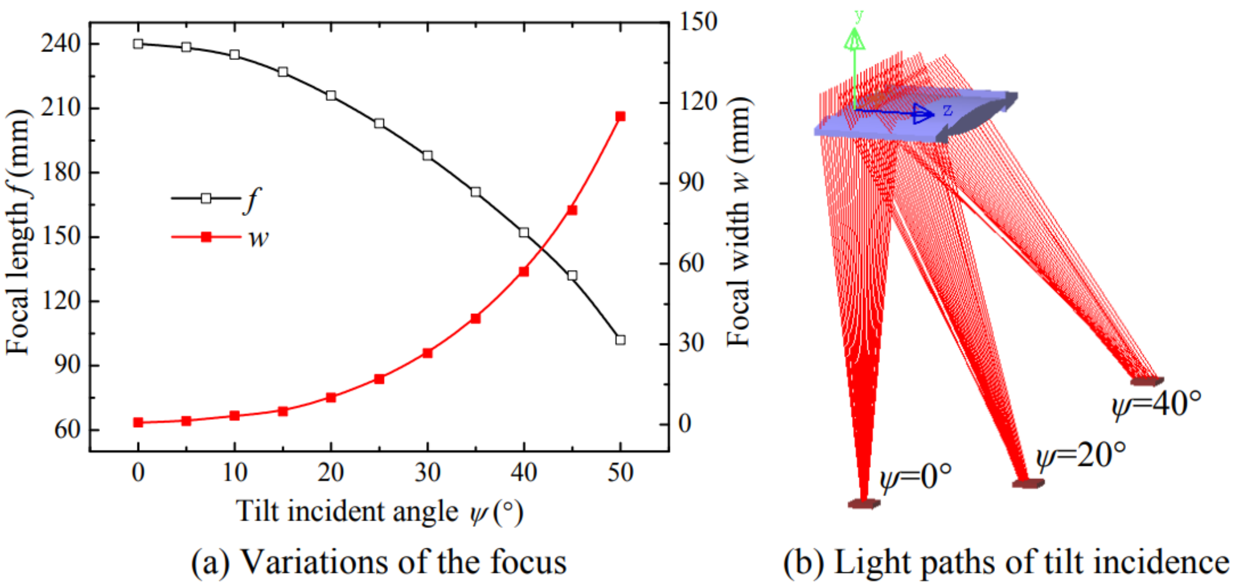


Figure 5 Unformed variations in ZFL focus [66].

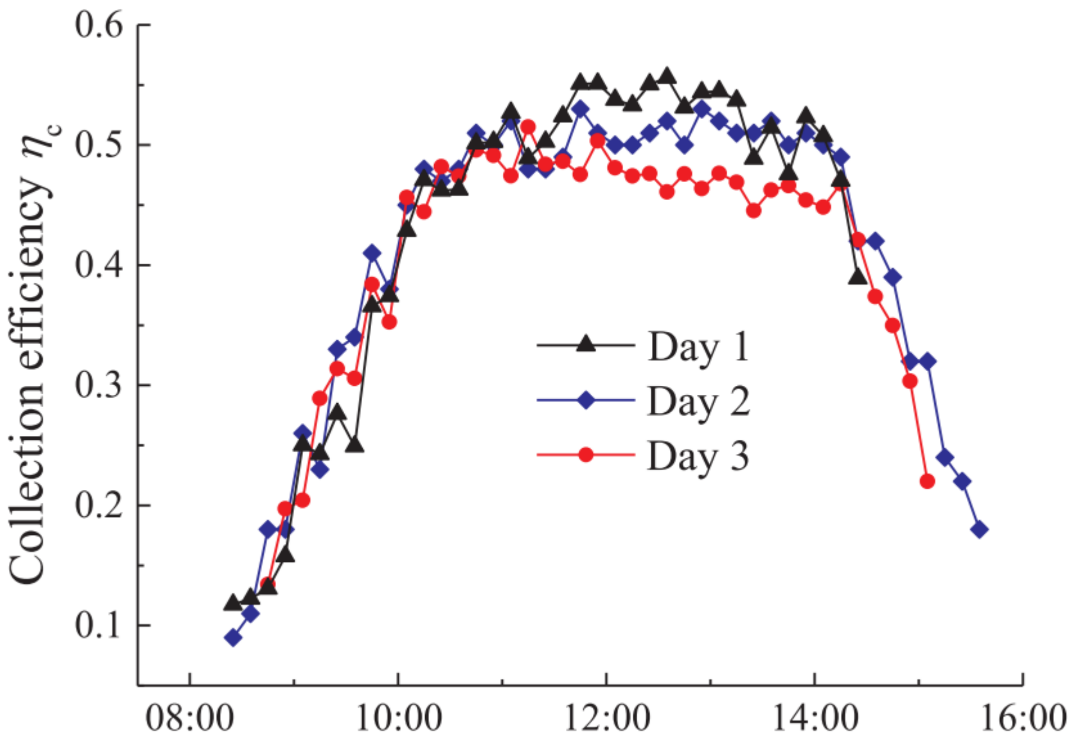


Figure 6 Chang of efficiency during the test time according to [67].

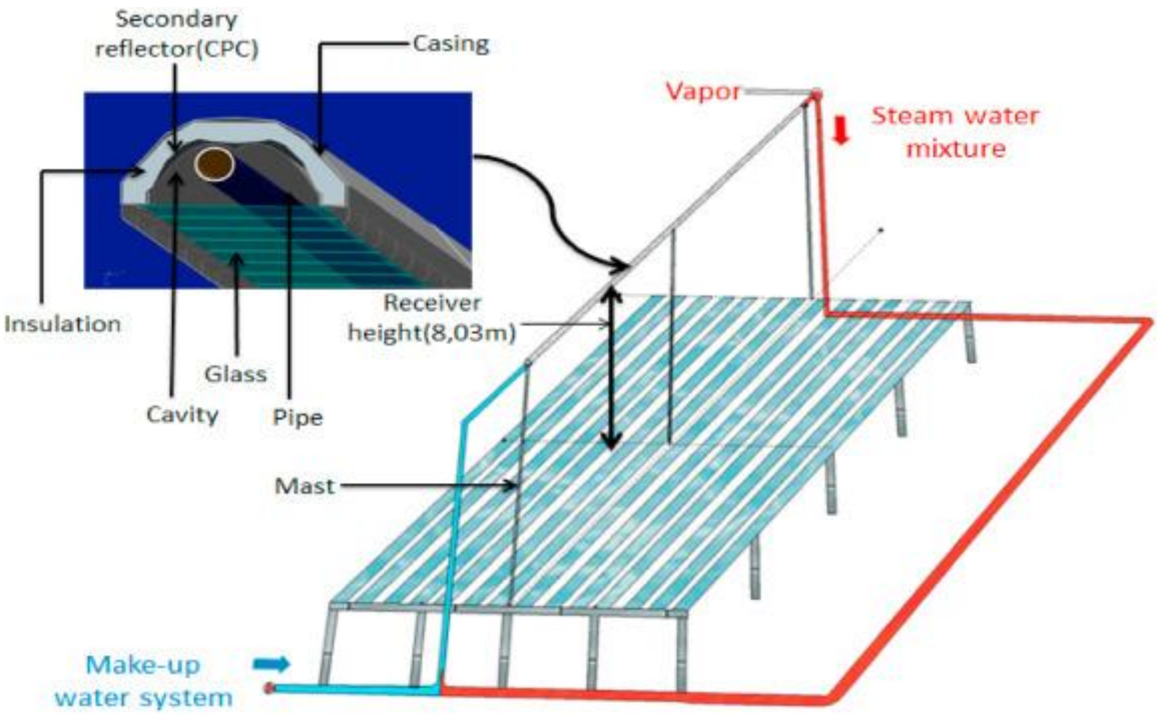


Figure 7 Layout set up according to [68].

2.4 Case Studies: Industrial and Residential Applications

In 2023, an improved solar prototype with LFC and a new design by Beltagy (2023) [71] made up a double parabolic concentrator (DPC), as shown in Figure 8. Several solar prototypes were tested in order to compare their efficiency. Accordingly, the prototype's spacing, aperture, focal length, and tube location were optimized using parametric research, and the double parabolic concentrator (DPC) functionality, as a secondary reflector, was evaluated. The numerous defining features of the solar field were described using Monte Carlo ray tracing (MCRT). With the new DPC design, the receiver's optical efficiency was close to 100%, meaning that the tube absorbed all photons that passed through the glass.

Additionally, a power gain of 10% to 13% was achieved in comparison to the old design. In 2023, Zhang et al. [72] examined an LFC coupling compound parabolic concentrator, or LFC-CPC, as revealed in Figure 9. To optimize the LFC-CPC surface structure, the MCRT method and the LFC theory were used. The LFC-light CPC's gathering performance experimental testing confirmed the theoretical design. The LFC-CPC is more weather-adaptive than the basic CPC due to its larger receiving angle and its ability to concentrate solar rays across all incidence angles efficiently. When compared to a basic CPC, the LFC-CPC has a longer beam radiation collection time and the highest daily effective in June, a rise of 36.1%. Due to a more uniform energy flux division on the absorber and a lower peak energy value on the absorber surface, an LFC-CPC is preferable to a basic one for long-term stable running.

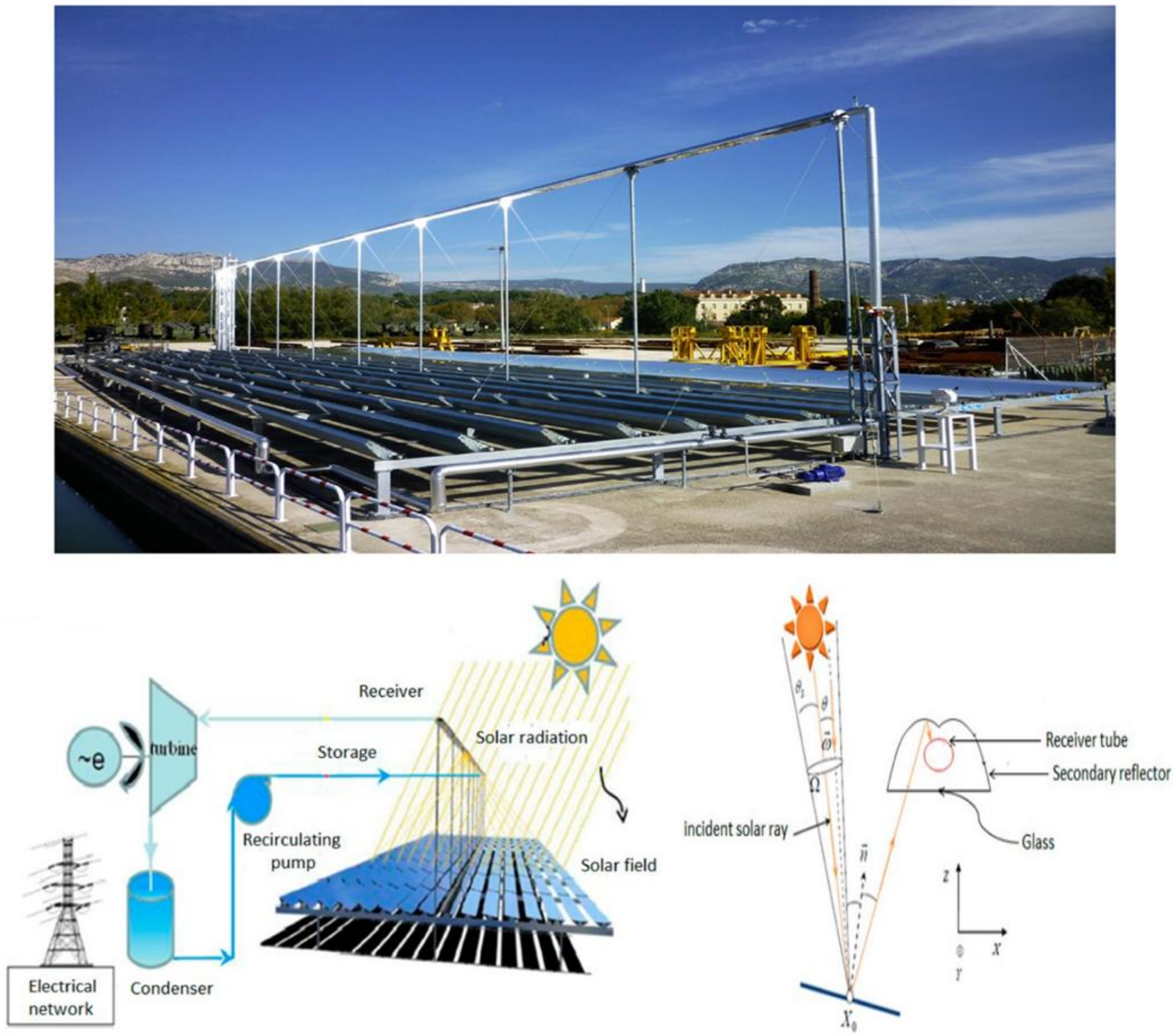
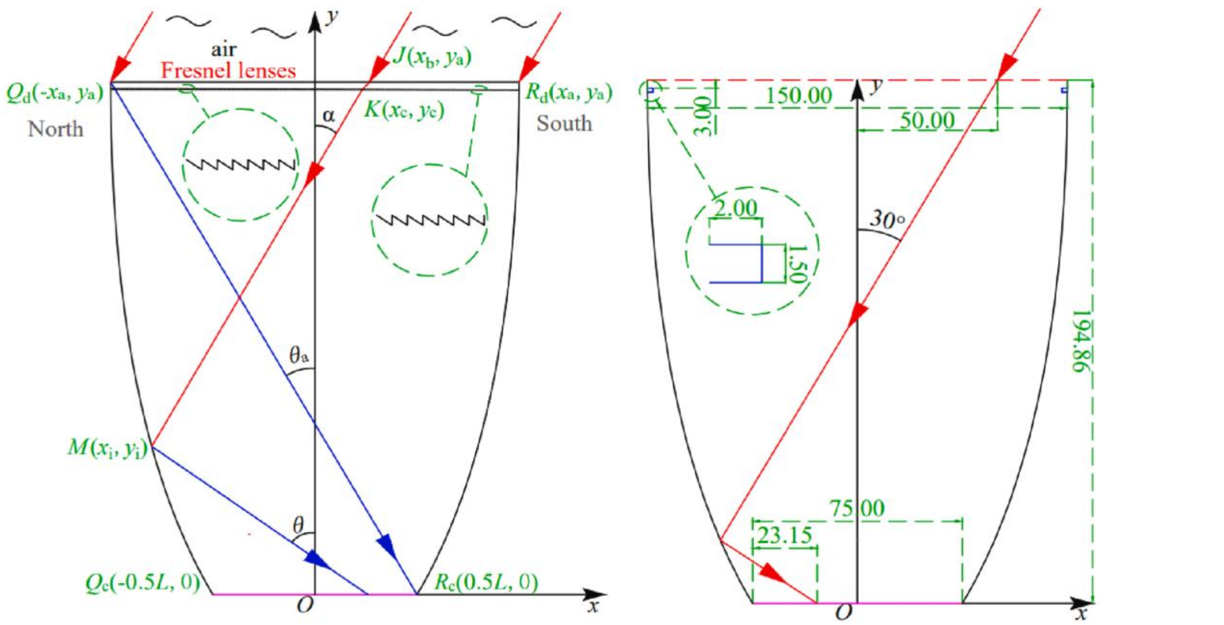


Figure 8 Layout set up according to [71]



(a) Fresnel lens coupling diagram. (b) Geometrical dimensions of plane absorber.

Figure 9 Structure diagram of CPC according to [72].

2.5 Solar Tracking Systems

Tracking systems mitigate end losses (energy loss at reflector edges) and enhance collector performance.

2.5.1 Mechanical Tracking Innovations

In 2017, the scalable LFC, a new design by Zhu et al. [50], was flexible and can adapt to different situations. To drastically reduce the impact of end losses, this structure might continuously tilt to match the solar altitude angle, as illustrated in Figure 10. As compared to the old method, the new design was able to reach the highest thermal efficiency of 64%, which was an improvement of almost 9%. As seen in Figure 11, a two-axis tracking system was later developed in 2018 by Yang et al. [73] to address the impacts of end loss. The main reflector can avoid end losses by sliding along the V-shaped rails. Results showed that, relative to the one-axis tracking system, the yearly average optical efficiency was improved by 8–50% (within the range of the normalized collection length and the local latitude). In 2021, a novel three-movement small-scale LFC with an open-loop solar tracking system was conceptualized, built, and tested by Barbón et al. [74], as shown in Figure 12. The system follows the sun's trajectory using offline data and astronomical equations; a Raspberry Pi and additional equipment such as a GPS control it. The system has an energy-lower levelized cost of 4.62%, a greater energy-to-area ratio of 78.46%, and can be automatically installed anywhere on Earth. It also provides 16.64% more energy than typical tracking systems.

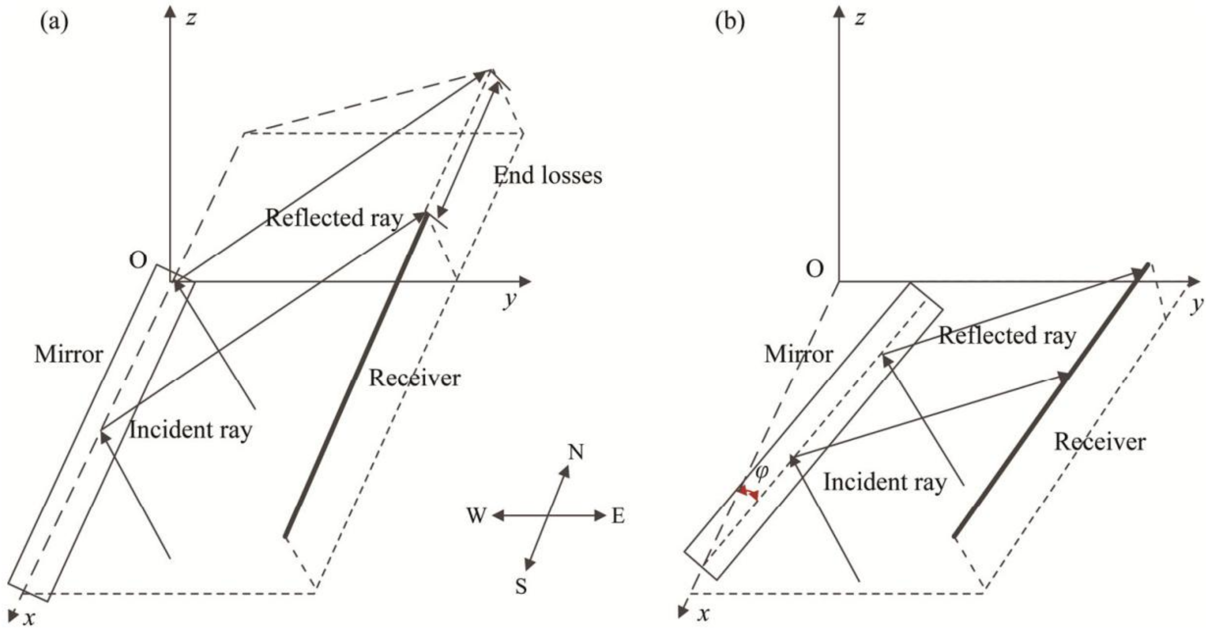


Figure 10 End loss elimination diagrams: (a) the traditional method, and (b) a novel method [50].

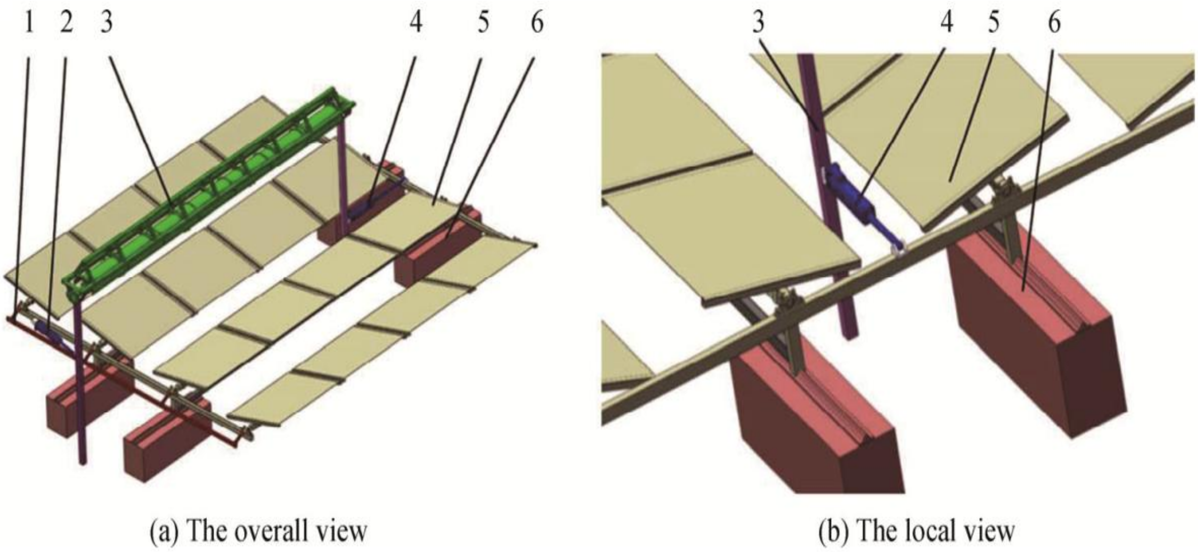


Figure 11 Schematic of a new LFC system with two-axis tracking [73].

Figure 12 Experimental setup of a small-scale LFC with an open-loop solar tracking system [74].

2.5.2 Receiver Optimization

In 2019, Bellos et al. [75] investigated the effects of repositioning and expanding the receiver, as illustrated in Figure 13. According to the findings, doubling the receiver length increases the annual performance by 50.3%. In addition, a yearly performance boost of around 20.2% is achievable with a 20% shift in receiver location. More importantly, it was demonstrated that by combining the impacts of moving and expanding the receiver, the optical performance may be improved by up to 48.7% with a relatively less investment. When it comes to the LFC with a short collector, this idea is crucial. In 2019, Babu et al. [76] used the millimeter-wave algorithms of the particle swarm optimization method to assess the efficiency of a horizontal absorber with reflectors of varied widths with respect to the concentration ratio (Figure 14). At a focal height of 0.96 m and an absorber width of 0.054 m, the highest concentration is attained. A 2-meter aperture and 58 reflectors of varied widths make up the system. At its highest, the concentration ratio reaches 32.6. The scorching months of March through June were used to test the experimental setup in India. Temperatures in storage tanks can reach up to 78 °C. The system reached 41.2% thermal efficiency.

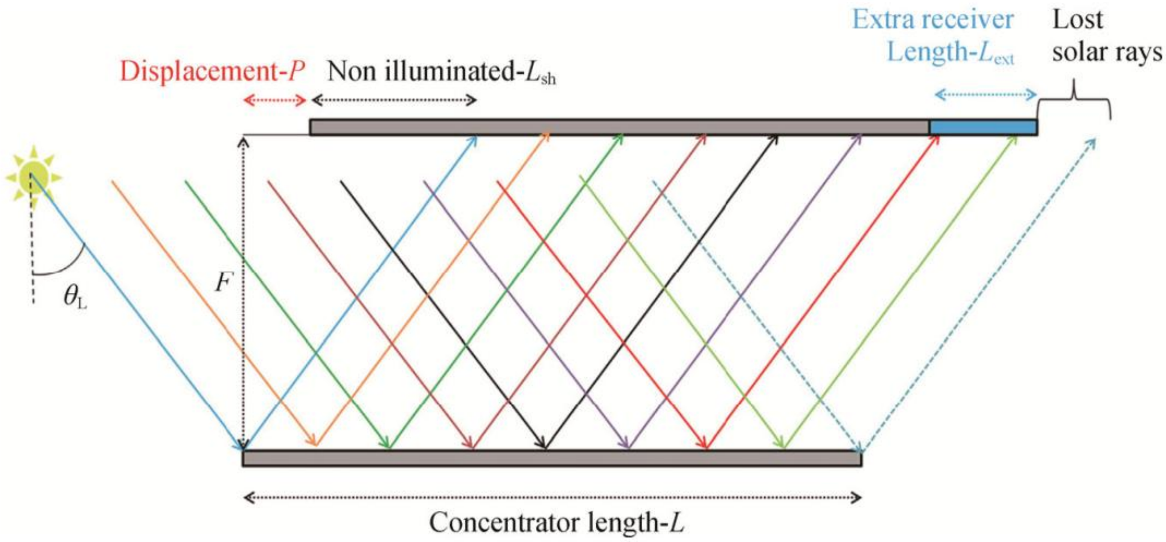


Figure 13 Layout of a receiver that extends and moves in a longitudinal mode [75].

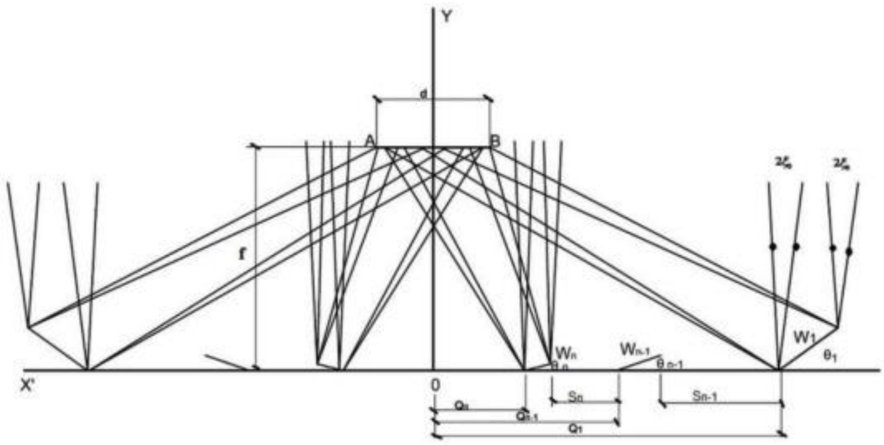


Figure 14 Concentrating System for LFC according to Babu et al. [76].

3. ANNULAR FRESNEL COLLECTORS

John Ericsson initially introduced the AFC in 1870 in the USA, where he utilized the technology to produce steam that powered a 373W engine [77]. The steam was directly generated in the collector. The AFC comprises an absorber, a parabolic reflector plate, and a concentric transparent cover. The absorber is constantly affixed to the parabolic concentrator focus. The concentric clear cover serves to insulate the tube of the absorber from heat loss, thereby maintaining a vacuum pressure. The parabolic concentrator is mounted on a rigid framework, which also supports the sunlight tracking mechanism to follow sun radiation effectively. Figure 2 illustrates the schematic representation of the AFC [78]. It aims to attain a high concentration ratio while maintaining a low-height device and low installation cost. The annular mirror series makes up the AFC, which is distinct from the LFC. Plus, AFC looks like a truncated cone with a circular base. A high concentration ratio and a single point of focus characterize the AFC. Due to its reflecting design and Fresnel assignment, the AFC is more cost-effective than the dish concentrator. There is a block loss in the AFC as well. The block loss also grows as the radius gets smaller.

One key difference between line focusing and the dish concentrator is the presence of a point-focusing beam. With point focusing, the geometrical concentration ratio is greater. The dish concentrator is known for its extended service life, simple installation, high concentration ratio, and efficient concentrating [79]. The dish concentrator has the potential to achieve a power plant efficiency of 31.25% [80]. A robust structure for the support frame is also necessary to minimize light loss, and the dish concentrator's inherent concentrating process requires it to use dual-axis tracking [81]. Simultaneously, there are numerous types of dish concentrators; the most common of these are single-dish and multi-dish concentrators, with the latter differing primarily in that it employs numerous mirrors to improve concentration.

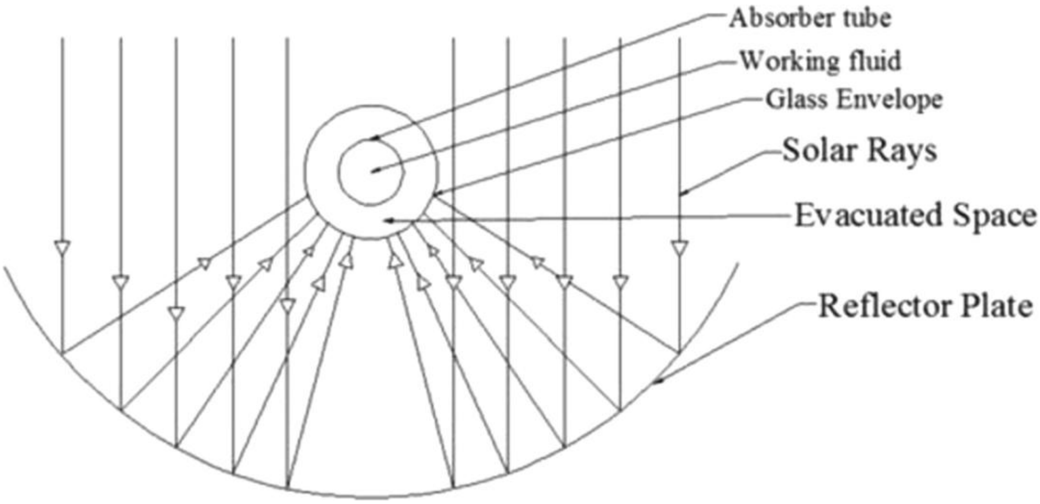


Figure 15 Schematic diagram of AFC [78].

3.1 Design and Performance

In 2020, Liang et al. [82] modeled the AFC with annular mirrors using MATLAB (Figure 16). In order to prevent end losses, such as those caused by inter-row shadowing and blocking, its mechanical construction was meticulously planned, including the placement, angle, and width of the mirrors. A deviation analysis was also carried out to disclose the AFC's concentration performance, and the performance with various design parameters was assessed. Within a range of 0.78 m in height and 1.72 m in diameter, the AFC achieved a concentrating ratio of 300. As the size of the structure increases, the AFC's performance varies linearly. Various deviations were seen in the radiation distribution and performance; at a tracking deviation angle of 0.5°, the receiving rate is 98.37%. In 2021, Liang et al. [83] developed and studied an AFCCFL, or annular Fresnel concentrator with a circular Fresnel lens. Figure 17 shows the main components of the AFCCFL, which included an AFC, a receiver, and a single circular Fresnel lens. Circular Fresnel lenses were positioned precisely in the center of the AFC. Research into simulations included the AFCCFL and the AFC. The results showed that compared to the AFC, the AFCCFL's receiver received 9.49% extra solar energy, 10.70% extra average irradiation, and 9.49% extra highest radiation.

Furthermore, a sun-collecting efficiency test bench was constructed to evaluate the AFCCFL. For comparison, experiments were carried out using the AFC and AFCCFL with variable and constant flows. According to their outcomes, the AFCCFL's thermal efficiency will be 20% higher compared to the AFC's in low-light situations. Figure 18 shows that under conditions of high solar radiation, both the AFCCFL and the AFC were able to achieve equal thermal efficiencies.

In 2024, an innovative distiller system that utilizes bottom-heating/interfacial evaporation driven by AFC was introduced by Chen et al. [84], as depicted in Figure 19. Through the use of a circular Fresnel lens and AFC, this system was able to increase the input solar energy. Because of its ability to evaporate water through capillary suction, the 1 D water supply wick was chosen as the interfacial evaporator. Because interfacial evaporation requires low ambient temperatures and concentrators, the distiller was further optimized in accordance with these parameters. Analyzed were the relative strengths of several distillers. In terms of cumulative freshwater production, the results demonstrated that bottom-heating distillation achieves 15.98 kg/(m^2·day), and interfacial evaporation achieves 21.25 kg/(m^2·day). This method outperformed the bottom-heating distiller in terms of maximum gain output ratio, coming in at 72.1%. Interfacial evaporation surfaces reached temperatures as high as 81.53 degrees.

Figure 16 AFC concentrator schematic [82].

Figure 17 Experimental AFCCFL images [83].

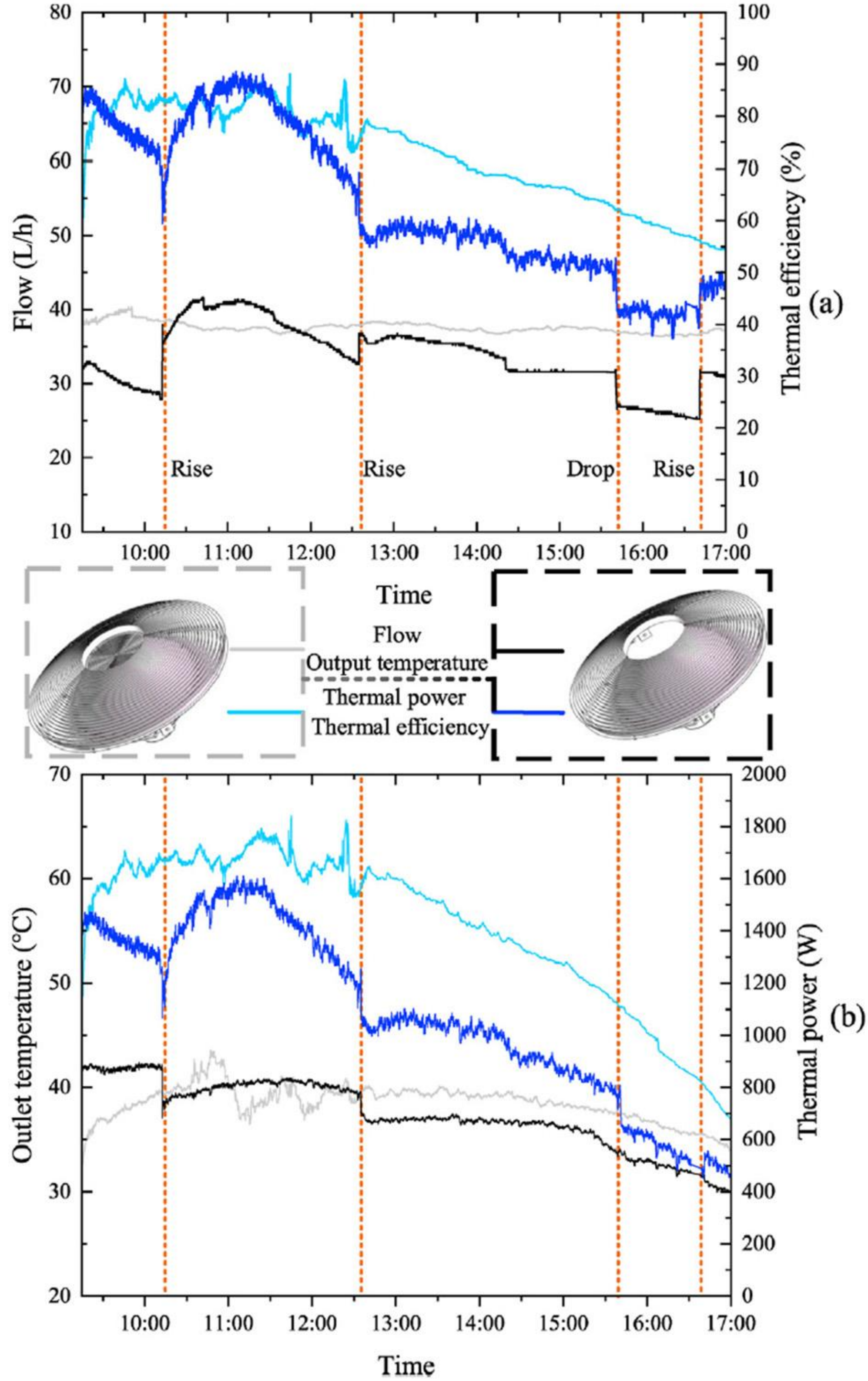


Figure 18 Thermal performance of (a) AFCC and (b) AFCCFL [83].

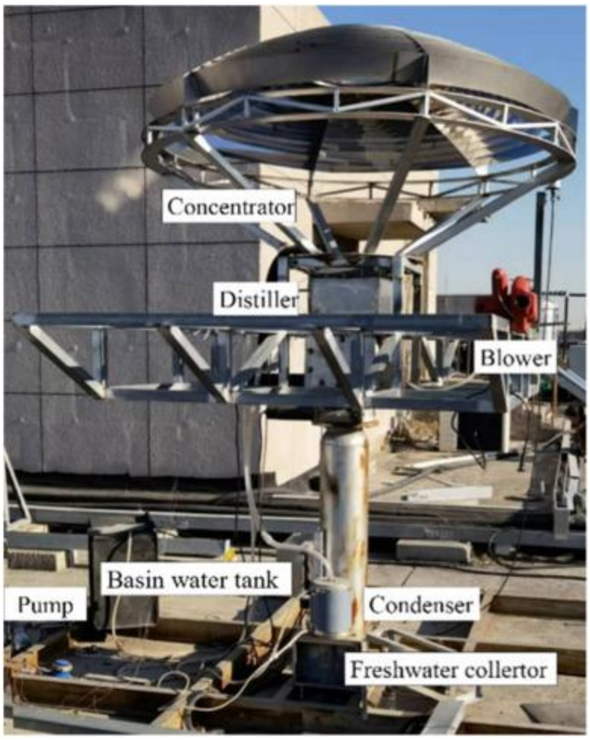


Figure 19 Experimental setup by Chen et al. [84].

In 2023, Abbas et al. [85] investigated the conical cavity thermal performance of a tube receiver in a solar parabolic dish concentrator system in relation to concentration ratios, as revealed in Figure 20. Energy and exergy efficiency at several concentration ratios (10.38, 20.76, and 31.15) were assessed using experimental and computational studies. The working fluid was water, with a 0.45 L/min flow rate. With a maximum concentration ratio of 31.15, energy efficiency averaged 65.81% and exergy efficiency 8.16%. The investigation revealed that despite lowering total heat loss, raising the concentration ratio improved the receiver's thermal performance. Strong agreement with experimental data was obtained via validation of the results using COMSOL Multiphysics® simulations. They offered insightful analysis on how to maximize solar thermal receiver design for high-efficiency energy conversion.

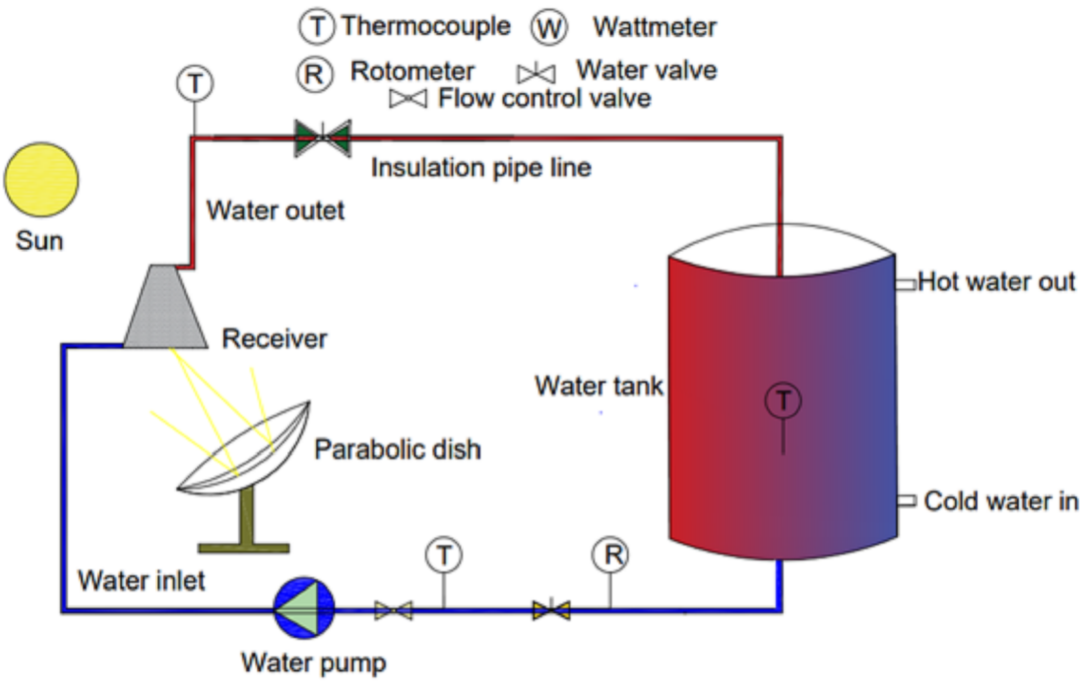
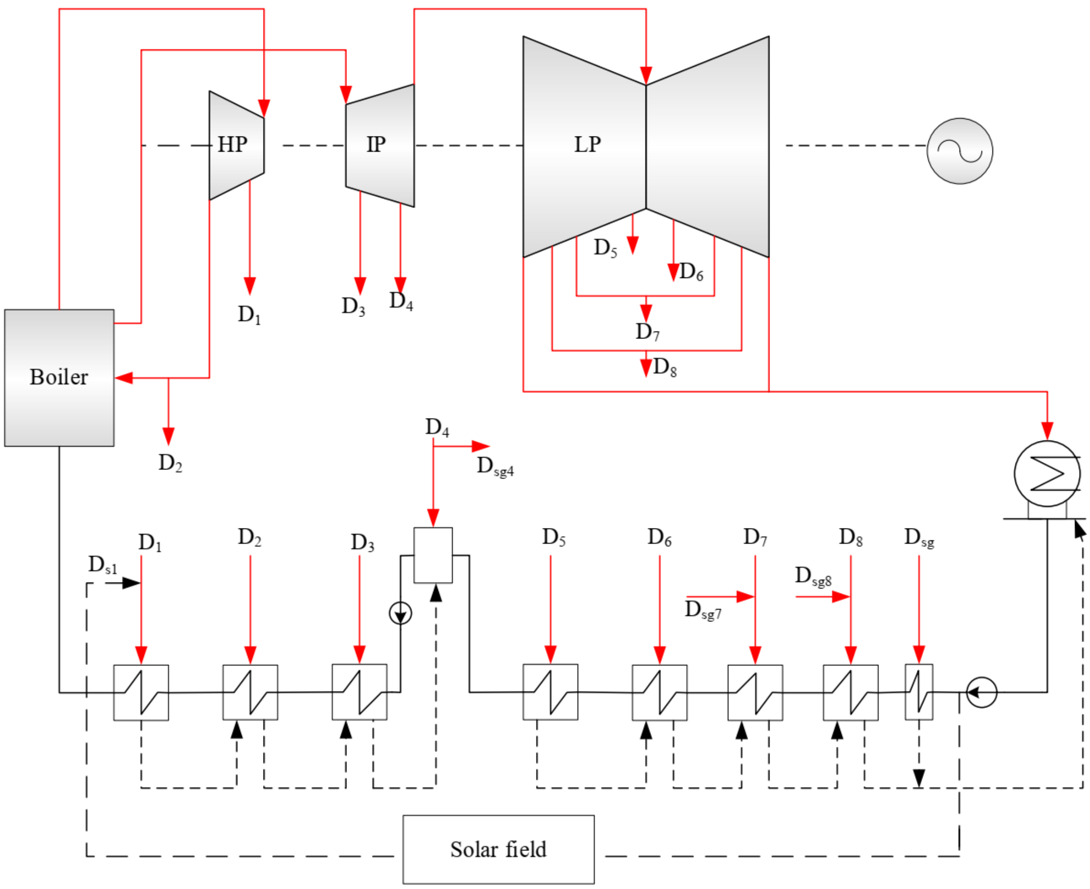


Figure 20 Schematic test rig of [85].

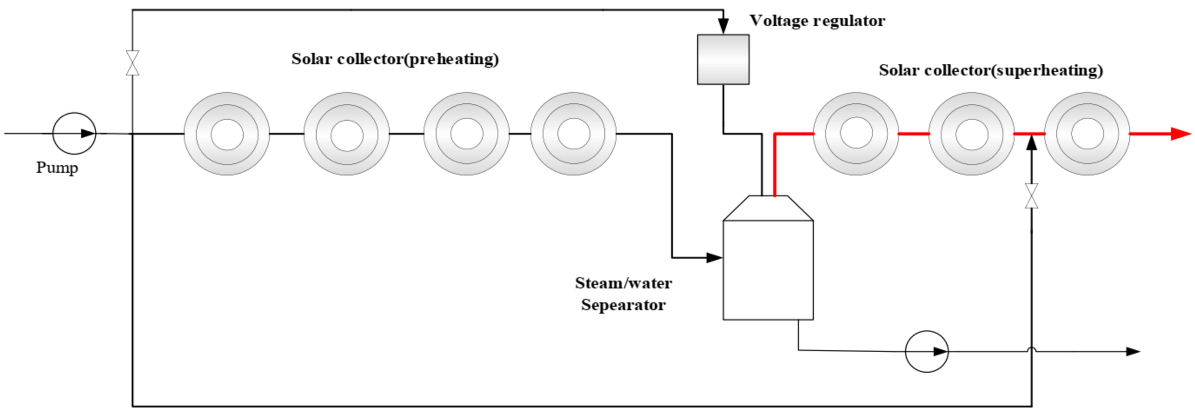
3.2 *Applications*

In 2021, Zhang et al. [86] presented the Solar Aided Power Generation (SAPG) system (Figure 21 (a)), which consists of traditional coal-fired units plus an AFC system. In order to replace the extraction steam used by the turbine with solar steam, an AFC system was implemented (Figure 21 (b)). Moreover, the range of tiny disturbance was achieved using the partial replacement method, hence necessitating a 20% increment in the extraction steam of the turbine from zero to one hundred percent. An analysis of the index of thermo-economic analysis and the tiny disturbance scope of a suggested SAPG system was presented. Depending on the amount of extraction steam and assessment index, the findings revealed that the system of SAPG can save energy. The scope of applicability for mild disturbances was also related to these parameters.

Under Mexican operational conditions, the performance of direct steam-generating solar power plants employing AFC and LFC was evaluated by González-Mora et al. [87]. Two 10 MW Rankine cycles with two and three steam extractions were investigated to evaluate 16 solar field configurations able to generate superheated steam at 400°C and 100 bar. They compared key metrics like thermal energy storage, pressure drop, and exergy efficiency, as well as energy and exergy efficiency. The findings revealed that in terms of efficiency and storage capacity, 14-loop AFC solar fields outperform LFC designs. Three-loop LFC systems were recommended, nevertheless, for space-limited installations or circumstances giving top priority to pressure reduction. The results shed light on how best to maximize solar field design for Mexican applications related to renewable energy.



(a)



(b)

Figure 21 SAPG layout by Zhang et al. [86].

4. COMPARATIVE STUDY OF SOLAR COLLECTORS

Table 1 emphasizes the differences between LFC and AFC based on 11 features. This review consolidates findings from several research papers and outlines the unique traits, benefits, and operational metrics of both technologies. Additional details and comparisons with respect to various factors, such as design structure, focusing type, optical efficiency, cost factors, land use, and temperature ranges, along with tracking systems, applications, recent advancements, and thermal efficiency, are presented. This table shows that whereas LFCs shine in moderate-temperature applications with reduced installation costs, AFCs are more suitable for high-temperature applications with improved concentration ratios.

Table 1: Comparison between LFC and AFC

Feature	**Linear Fresnel Collector (LFC)**	**Annular Fresnel Collector (AFC)**
Design Structure	- Linear array of narrow mirror strips at ground level [60]	- Concentric transparent cover and parabolic reflector plate [77,78]
Focusing Type	- Line focusing	- Point focusing with single focus
Optical Efficiency	- 20-30% lower than parabolic trough collectors [22–25]	- Higher concentration ratios possible due to point focusing design
Cost Factors	- About 52% cost of parabolic trough collectors	- More cost-effective than dish concentrators
Land Use	- Efficient land use with compact design	- Circular arrangement for space optimization
Temperature Range	- Suitable for moderate temperatures (100-300°C)	- Capable of higher temperatures
Tracking System	- Single or dual-axis tracking possible [73,74]	- Typically requires dual-axis tracking
Applications	- Solar thermal power plants	- Solar aided power generation

	- Industrial process heat	- High-temperature applications
Recent Innovations	- Zoomable Fresnel lens technology	- Integration with circular Fresnel lens
Thermal Efficiency	- Maximum overall efficiency ~20%	- Thermal efficiency 93.6-97.2% reported

5. CHALLENGES AND LIMITATIONS

i. **Optical Losses**: Reflection, absorption, and diffraction account for up to 47% of energy loss in LFCs [57]. Anti-reflective coatings and prismatic lens designs are under investigation to mitigate these losses.

ii. **Economic Barriers**: High initial costs for AFCs ($3–5/W) and tracking systems hinder widespread adoption [82]. Economies of scale and automated manufacturing could reduce costs by 30–40% by 2030.

iii. **Scalability**: Large-scale Fresnel systems face alignment and maintenance challenges. Robotic cleaning systems and AI-driven alignment tools are emerging solutions.

iv. **Environmental Factors**: Dust accumulation reduces optical efficiency by 10–15% in arid regions [18]. Self-cleaning hydrophobic lens coatings are being tested to address this issue.

6. CONCLUSION

Fresnel lens technology has redefined solar thermal collection by enabling efficient, compact, and versatile systems. LFCs and AFCs demonstrate significant potential in industrial, agricultural, and desalination applications, outperforming traditional collectors in specific niches. While challenges like optical losses and costs persist, ongoing innovations in design, tracking, and material science promise to unlock broader adoption. This review underscores the need for interdisciplinary research to address technical limitations and accelerate the global transition to solar energy.

7. REFERENCES

[1] S.W. Sharshir, M. Ismail, A.W. Kandeal, F.B. Baz, A. Eldesoukey, M.M. Younes, Improving thermal, economic, and environmental performance of solar still using floating coal, cotton fabric, and carbon black nanoparticles, Sustain. Energy Technol. Assessments. 48 (2021). https://doi.org/10.1016/j.seta.2021.101563.

[2] D. Mevada, H. Panchal, H.A. ElDinBastawissi, M. Elkelawy, K. Sadashivuni, D. Ponnamma, N. Thakar, S.W. Sharshir, Applications of evacuated tubes collector to harness the solar energy: a review, Int. J. Ambient Energy. 43 (2022) 344–361. https://doi.org/10.1080/01430750.2019.1636886.

[3] J. Wang, Z. Yin, J. Qi, G. Ma, X. Liu, Medium-temperature Solar Collectors with All-glass Solar Evacuated Tubes, Energy Procedia. 70 (2015) 126–129. https://doi.org/10.1016/J.EGYPRO.2015.02.107.

[4] E. Bellos, E. Mathioulakis, C. Tzivanidis, V. Belessiotis, K.A. Antonopoulos, Experimental and numerical investigation of a linear Fresnel solar collector with flat plate receiver, Energy Convers. Manag. 130 (2016) 44–59. https://doi.org/10.1016/J.ENCONMAN.2016.10.041.

[5] G. Francia, Pilot plants of solar steam generating stations, Sol. Energy. 12 (1968) 51–64. https://doi.org/10.1016/0038-092X(68)90024-8.

[6] D.G. Di Canio, W.J. Treytl, F.A. Jur, C.D. Watson, Line focus solar thermal central receiver research study. Final report, April 30, 1977-March 30, 1979, (1979). https://doi.org/10.2172/5535434.

[7] R.N. Singh, S.S. Mathur, T.C. Kandpal, Some geometrical design aspects of a linear fresnel reflector concentrator, Int. J. Energy Res. 4 (1980) 59–67. https://doi.org/10.1002/ER.4440040107.

[8] A.K. Singhal, M.S. Sharma, B.S. Negi, S.S. Mathur, Performance testing of a linear fresnel reflector, Int. J. Energy Res. 10 (1986) 39–46. https://doi.org/10.1002/ER.4440100105.

[9] B.S. Negi, T.C. Kandpal, S.S. Mathur, Designs and performance characteristics of a linear fresnel reflector solar concentrator with a flat vertical absorber, Sol. Wind Technol. 7 (1990) 379–392. https://doi.org/10.1016/0741-983X(90)90023-U.

[10] S.S. Mathur, T.C. Kandpal, B.S. Negi, Optical design and concentration characteristics of linear Fresnel reflector solar concentrators—II. Mirror elements of equal width, Energy Convers. Manag. 31 (1991) 221–232. https://doi.org/10.1016/0196-8904(91)90076-U.

[11] B.S. Negi, S.S. Mathur, T.C. Kandpal, Optical and thermal performance evaluation of a linear fresnel reflector solar concentrator, Sol. Wind Technol. 6 (1989) 589–593. https://doi.org/10.1016/0741-983X(89)90095-7.

[12] H. Ries, J.M. Gordon, Tailored edge-ray concentrators as ideal second stages for Fresnel reflectors, Appl. Opt. Vol. 32, Issue 13, Pp. 2243-2251. 32 (1993) 2243–2251. https://doi.org/10.1364/AO.32.002243.

[13] D. Feuermann, J.M. Gordon, Analysis of a Two-Stage Linear Fresnel Reflector Solar Concentrator, J. Sol. Energy Eng. 113 (1991) 272–279. https://doi.org/10.1115/1.2929973.

[14] D.R. Mills, G.L. Morrison, Compact Linear Fresnel Reflector solar thermal powerplants, Sol. Energy. 68 (2000) 263–283. https://doi.org/10.1016/S0038-092X(99)00068-7.

[15] R. Abbas, J. Muñoz-Antón, M. Valdés, J.M. Martínez-Val, High concentration linear Fresnel reflectors, Energy Convers. Manag. 72 (2013) 60–68. https://doi.org/10.1016/J.ENCONMAN.2013.01.039.

[16] F.J. Pino, R. Caro, F. Rosa, J. Guerra, Experimental validation of an optical and thermal model of a linear Fresnel collector system, Appl. Therm. Eng. 50 (2013) 1463–1471. https://doi.org/10.1016/J.APPLTHERMALENG.2011.12.020.

[17] A. Hofer, D. Büchner, K. Kramer, S. Fahr, A. Heimsath, W.J. Platzer, S. Scholl, Comparison of Two Different (Quasi-) Dynamic Testing Methods for the Performance Evaluation of a Linear Fresnel Process Heat Collector, Energy Procedia. 69 (2015) 84–95. https://doi.org/10.1016/J.EGYPRO.2015.03.011.

[18] M.J. Montes, C. Rubbia, R. Abbas, J.M. Martínez-Val, A comparative analysis of configurations of linear Fresnel collectors for concentrating solar power, Energy. 73 (2014) 192–203. https://doi.org/10.1016/J.ENERGY.2014.06.010.

[19] H. Beltagy, D. Semmar, C. Lehaut, N. Said, Theoretical and experimental performance analysis of a Fresnel type solar concentrator, Renew. Energy. 101 (2017) 782–793. https://doi.org/10.1016/J.RENENE.2016.09.038.

[20] E. Bellos, C. Tzivanidis, A. Papadopoulos, Daily, monthly and yearly performance of a linear Fresnel reflector, Sol. Energy. 173 (2018) 517–529. https://doi.org/10.1016/J.SOLENER.2018.08.008.

[21] A.K. Pandey, R.K. R., M. Samykano, Solar energy: direct and indirect methods to harvest usable energy, Dye. Sol. Cells. (2022) 1–24. https://doi.org/10.1016/B978-0-12-818206-2.00007-4.

[22] G. Morin, J. Dersch, W. Platzer, M. Eck, A. Häberle, Comparison of Linear Fresnel and Parabolic Trough Collector power plants, Sol. Energy. 86 (2012) 1–12. https://doi.org/10.1016/J.SOLENER.2011.06.020.

[23] A. Giostri, M. Binotti, P. Silva, E. MacChi, G. Manzolini, Comparison of two linear collectors in solar thermal plants: Parabolic trough versus Fresnel, J. Sol. Energy Eng. Trans. ASME. 135 (2013). https://doi.org/10.1115/1.4006792/443616.

[24] G. Cau, D. Cocco, Comparison of Medium-size Concentrating Solar Power Plants based on Parabolic Trough and Linear Fresnel Collectors, Energy Procedia. 45 (2014) 101–110. https://doi.org/10.1016/J.EGYPRO.2014.01.012.

[25] R. Abbas, M. Valdés, M.J. Montes, J.M. Martínez-Val, Design of an innovative linear Fresnel collector by means of optical performance optimization: A comparison with parabolic trough collectors for different latitudes, Sol. Energy. 153 (2017) 459–470. https://doi.org/10.1016/J.SOLENER.2017.05.047.

[26] M. Lin, K. Sumathy, Y.J. Dai, R.Z. Wang, Y. Chen, Experimental and theoretical analysis on a linear Fresnel reflector solar collector prototype with V-shaped cavity receiver, Appl. Therm. Eng. 51 (2013) 963–972. https://doi.org/10.1016/J.APPLTHERMALENG.2012.10.050.

[27] J.R. Mahan, The Monte Carlo Ray-Trace Method in Radiation Heat Transfer and Applied Optics, (2019). https://doi.org/10.1115/1.861MAH.

[28] A. Heimsath, G. Bern, D. Van Rooyen, P. Nitz, Quantifying Optical Loss Factors of Small Linear Concentrating Collectors for Process Heat Application, Energy Procedia. 48 (2014) 77–86. https://doi.org/10.1016/J.EGYPRO.2014.02.010.

[29] M. Fossa, A. Boccalatte, S. Memme, Solar Fresnel modelling, geometry enhancement and 3D ray tracing analysis devoted to different energy efficiency definitions and applied to a real facility, Sol. Energy. 216 (2021) 75–89. https://doi.org/10.1016/J.SOLENER.2020.12.047.

[30] S. Memme, M. Fossa, Ray tracing analysis of linear Fresnel concentrators and the effect of plant azimuth on their optical efficiency, Renew. Energy. 216 (2023) 119121. https://doi.org/10.1016/J.RENENE.2023.119121.

[31] A.V. Santos, D. Canavarro, P. Horta, M. Collares-Pereira, An analytical method for the optical analysis of Linear Fresnel Reflectors with a flat receiver, Sol. Energy. 227 (2021) 203–216. https://doi.org/10.1016/J.SOLENER.2021.08.085.

[32] R. Abbas, J.M. Martínez-Val, A comprehensive optical characterization of linear Fresnel collectors by means of an analytic study, Appl. Energy. 185 (2017) 1136–1151. https://doi.org/10.1016/J.APENERGY.2016.01.065.

[33] G. Zhu, Development of an analytical optical method for linear Fresnel collectors, Sol. Energy. 94 (2013) 240–252. https://doi.org/10.1016/J.SOLENER.2013.05.003.

[34] J. Chaves, M. Collares-Pereira, Etendue-matched two-stage concentrators with multiple receivers, Sol. Energy. 84 (2010) 196–207. https://doi.org/10.1016/J.SOLENER.2009.10.022.

[35] R. Abbas, J.M. Martínez-Val, Analytic optical design of linear Fresnel collectors with variable widths and shifts of mirrors, Renew. Energy. 75 (2015) 81–92. https://doi.org/10.1016/J.RENENE.2014.09.029.

[36] V. Sharma, S. Khanna, J.K. Nayak, S.B. Kedare, Effects of shading and blocking in compact linear fresnel reflector field, Energy. 94 (2016) 633–653. https://doi.org/10.1016/J.ENERGY.2015.10.098.

[37] V. Sharma, J.K. Nayak, S.B. Kedare, Comparison of line focusing solar concentrator fields considering shading and blocking, Sol. Energy. 122 (2015) 924–939. https://doi.org/10.1016/J.SOLENER.2015.10.011.

[38] V. Sharma, J.K. Nayak, S.B. Kedare, Effects of shading and blocking in linear Fresnel reflector field, Sol. Energy. 113 (2015) 114–138. https://doi.org/10.1016/J.SOLENER.2014.12.026.

[39] R. Abbas, M.J. Montes, M. Piera, J.M. Martínez-Val, Solar radiation concentration features in Linear Fresnel Reflector arrays, Energy Convers. Manag. 54 (2012) 133–144. https://doi.org/10.1016/J.ENCONMAN.2011.10.010.

[40] S. Benyakhlef, A. Al Mers, O. Merroun, A. Bouatem, N. Boutammachte, S. El Alj, H. Ajdad, Z. Erregueragui, E. Zemmouri, Impact of heliostat curvature on optical performance of Linear Fresnel solar concentrators, Renew. Energy. 89 (2016) 463–474. https://doi.org/10.1016/J.RENENE.2015.12.018.

[41] A.V. Santos, D. Canavarro, P. Horta, M. Collares-Pereira, On the comparison of parabolical and cylindrical primary mirrors for linear Fresnel solar concentrators, Renew. Energy. 218 (2023) 119380. https://doi.org/10.1016/J.RENENE.2023.119380.

[42] Y.L. He, K. Wang, Y. Qiu, B.C. Du, Q. Liang, S. Du, Review of the solar flux distribution in concentrated solar power: Non-uniform features, challenges, and solutions, Appl. Therm. Eng. 149 (2019) 448–474. https://doi.org/10.1016/J.APPLTHERMALENG.2018.12.006.

[43] Y. Qiu, M.J. Li, K. Wang, Z. Bin Liu, X.D. Xue, Aiming strategy optimization for uniform flux distribution in the receiver of a linear Fresnel solar reflector using a multi-objective genetic algorithm, Appl. Energy. 205 (2017) 1394–1407. https://doi.org/10.1016/J.APENERGY.2017.09.092.

[44] G. Walker, V.B. Tw, P. Gauché, A METHOD OF INCREASING COLLECTOR APERTURE IN

LINEAR FRESNEL SOLAR CONCENTRATORS AT HIGH ZENITH ANGLES, (2012).

[45] M. Hongn, S.F. Larsen, M. Gea, M. Altamirano, Least square based method for the estimation of the optical end loss of linear Fresnel concentrators, Sol. Energy. 111 (2015) 264–276. https://doi.org/10.1016/J.SOLENER.2014.10.042.

[46] H. Lv, K. Chen, P. Chen, X. Wang, L. Wen, Optical Efficiency Analysis of Primary Mirror in LFR-CSP, J. Phys. Conf. Ser. 2254 (2022) 012030. https://doi.org/10.1088/1742-6596/2254/1/012030.

[47] A.N. Zadeh, M. Ameri, A. Shojaei, I.B. Askari, Optical Efficiency of Linear Fresnel Reflectors in Fixed, Variable and Optimal Distance between Mirrors: Theoretical and Experimental Studies, Int. J. Eng. 37 (2024) 283–297. https://doi.org/10.5829/IJE.2024.37.02B.06.

[48] J. Zhu, H. Huang, Design and thermal performances of Semi-Parabolic Linear Fresnel Reflector solar concentration collector, Energy Convers. Manag. 77 (2014) 733–737. https://doi.org/10.1016/J.ENCONMAN.2013.10.015.

[49] Y. Zhu, J. Shi, Y. Li, L. Wang, Q. Huang, G. Xu, Design and experimental investigation of a stretched parabolic linear Fresnel reflector collecting system, Energy Convers. Manag. 126 (2016) 89–98. https://doi.org/10.1016/J.ENCONMAN.2016.07.073.

[50] Y. Zhu, J. Shi, Y. Li, L. Wang, Q. Huang, G. Xu, Design and thermal performances of a scalable linear Fresnel reflector solar system, Energy Convers. Manag. 146 (2017) 174–181. https://doi.org/10.1016/J.ENCONMAN.2017.05.031.

[51] J. Zhu, Z. Chen, Optical design of compact linear fresnel reflector systems, Sol. Energy Mater. Sol. Cells. 176 (2018) 239–250. https://doi.org/10.1016/J.SOLMAT.2017.12.016.

[52] E. Bellos, C. Tzivanidis, Development of analytical expressions for the incident angle modifiers of a linear Fresnel reflector, Sol. Energy. 173 (2018) 769–779. https://doi.org/10.1016/J.SOLENER.2018.08.019.

[53] A. Boccalatte, M. Fossa, C. Ménézo, Calculation of the incidence angle modifier of a Linear Fresnel Collector: The proposed declination and zenith angle model compared to the biaxial factored approach, Renew. Energy. 185 (2022) 123–138. https://doi.org/10.1016/J.RENENE.2021.12.017.

[54] S. Memme, M. Fossa, A novel approach for incidence angle modifier calculation of arbitrarily oriented linear Fresnel collectors: Theory, simulations and case studies, Renew. Energy. 222 (2024) 119857. https://doi.org/10.1016/J.RENENE.2023.119857.

[55] F.L. Rashid, M.A. Al-Obaidi, A.J. Mahdi, A. Ameen, Advancements in Fresnel Lens Technology across Diverse Solar Energy Applications: A Comprehensive Review, Energies 2024, Vol. 17, Page 569. 17 (2024) 569. https://doi.org/10.3390/EN17030569.

[56] W. Jang, S. Kim, D. Lee, K.H. Lee, Y.G. Kim, A. Park, Y. Park, J.H. Lee, Design of partitioned linear Fresnel lens for medium-concentrated PV and its performance, AIP Conf. Proc. 1616 (2014) 67–71. https://doi.org/10.1063/1.4897030.

[57] S. Perini, X. Tonnellier, P. King, C. Sansom, Theoretical and experimental analysis of an innovative dual-axis tracking linear Fresnel lenses concentrated solar thermal collector, Sol. Energy. 153 (2017) 679–690. https://doi.org/10.1016/J.SOLENER.2017.06.010.

[58] M.F. Kaddoura, J. Zeaiter, Application of thermal energy storage with point focus Fresnel lens concentrator: Numerical and experimental analysis, J. Energy Storage. 26 (2019) 101008. https://doi.org/10.1016/J.EST.2019.101008.

[59] H. Wang, Comparative Study of a Fixed-Focus Fresnel Lens Solar Concentrator/Conical Cavity Receiver System with and without Glass Cover Installed in a Solar Cooker, Sustain. 2023, Vol. 15, Page 9450. 15 (2023) 9450. https://doi.org/10.3390/SU15129450.

[60] E. Bellos, I. Skaltsas, O. Pliakos, C. Tzivanidis, Energy and financial investigation of a cogeneration system based on linear Fresnel reflectors, Energy Convers. Manag. 198 (2019) 111821. https://doi.org/10.1016/J.ENCONMAN.2019.111821.

[61] G. Wu, Q. Yang, Y. Zhang, H. Fang, C. Feng, H. Zheng, Energy and optical analysis of photovoltaic thermal integrated with rotary linear curved Fresnel lens inside a Chinese solar greenhouse, Energy. 197 (2020) 117215. https://doi.org/10.1016/J.ENERGY.2020.117215.

[62] T.I. Abdelsalam, B. Abdel-Mesih, An experimental study on the effect of using fresnel lenses on the performance of solar stills, Springer Proc. Phys. 155 (2014) 353–362. https://doi.org/10.1007/978-3-319-05521-3_45/FIGURES/6.

[63] S.I. Palomino-Resendiz, D.A. Flores-Hernández, N. Lozada-Castillo, L. Guzmán-Vargas, A. Luviano-Juárez, Design and implementation of a robotic active solar distiller based on a Fresnel concentrator and a photovoltaic system, Energy Convers. Manag. 166 (2018) 637–647. https://doi.org/10.1016/J.ENCONMAN.2018.04.069.

[64] C. Sansom, X. Tonnellier, P. King, H. Almond, The techno-economic optimization of a 100MW e CSP-desalination plant in Arandis, AIP Conf. Proc. 2126 (2019) 230003. https://doi.org/10.1063/1.5117767.

[65] W. Gang, Y. Qichang, Z. Hongfei, Z. Yi, F. Hui, J. Rihui, Direct utilization of solar linear Fresnel reflector on multi-effect eccentric horizontal tubular still with falling film, Energy. 170 (2019) 170–184. https://doi.org/10.1016/J.ENERGY.2018.12.150.

[66] X. Ma, S. Liang, R. Jin, H. Zheng, Characteristics of a zoomable Fresnel lens (ZFL) used for solar concentration, Energy. 194 (2020) 116698. https://doi.org/10.1016/J.ENERGY.2019.116698.

[67] X. Ma, R. Jin, S. Liang, S. Liu, H. Zheng, Analysis on an optimal transmittance of Fresnel lens as solar concentrator, Sol. Energy. 207 (2020) 22–31. https://doi.org/10.1016/J.SOLENER.2020.06.071.

[68] H. Beltagy, The effect of glass on the receiver and the use of two absorber tubes on optical performance of linear fresnel solar concentrators, Energy. 224 (2021) 120111. https://doi.org/10.1016/J.ENERGY.2021.120111.

[69] M. Gupta, A. Bhatnagar, A.K. Dubey, V. Kumar, D.S. Mehta, Dual Fresnel lens and segmented mirrors based efficient solar concentration system without tracking sun for solar thermal energy generation, Energy Sustain. Dev. 66 (2022) 201–208. https://doi.org/10.1016/J.ESD.2021.12.008.

[70] A.R. Jensen, I. Sifnaios, G.P. Caringal, S. Furbo, J. Dragsted, Thermal performance assessment of the world's first solar thermal Fresnel lens collector field, Sol. Energy. 237 (2022) 447–455. https://doi.org/10.1016/J.SOLENER.2022.01.067.

[71] H. Beltagy, A secondary reflector geometry optimization of a Fresnel type solar concentrator, Energy Convers. Manag. 284 (2023) 116974. https://doi.org/10.1016/J.ENCONMAN.2023.116974.

[72] X. Zhang, J. Li, J. Chen, F. Chen, Preliminary investigation on optical performance of linear fresnel lens coupled compound parabolic concentrator, Energy. 278 (2023) 127910. https://doi.org/10.1016/J.ENERGY.2023.127910.

[73] M. Yang, Y. Zhu, R.A. Taylor, End losses minimization of linear Fresnel reflectors with a simple, two-axis mechanical tracking system, Energy Convers. Manag. 161 (2018) 284–293. https://doi.org/10.1016/J.ENCONMAN.2018.01.082.

[74] A. Barbón, J.A. Fernández-Rubiera, L. Martínez-Valledor, A. Pérez-Fernández, L. Bayón, Design and construction of a solar tracking system for small-scale linear Fresnel reflector with three movements, Appl. Energy. 285 (2021) 116477. https://doi.org/10.1016/J.APENERGY.2021.116477.

[75] E. Bellos, C. Tzivanidis, M.A. Moghimi, Reducing the optical end losses of a linear Fresnel reflector using novel techniques, Sol. Energy. 186 (2019) 247–256. https://doi.org/10.1016/J.SOLENER.2019.05.020.

[76] M. Babu, S.S. Raj, A. Valan Arasu, Experimental analysis on Linear Fresnel reflector solar concentrating hot water system with varying width reflectors, Case Stud. Therm. Eng. 14 (2019) 100444. https://doi.org/10.1016/J.CSITE.2019.100444.

[77] J. Ericsson, The sun motor and the sun's temperature, Nature. 29 (1884) 217–219. https://doi.org/10.1038/029217A0.

[78] V.K. Jebasingh, G.M.J. Herbert, A review of solar parabolic trough collector, Renew. Sustain. Energy Rev. 54 (2016) 1085–1091. https://doi.org/10.1016/J.RSER.2015.10.043.

[79] A. Poullikkas, G. Kourtis, I. Hadjipaschalis, Parametric analysis for the installation of solar dish technologies in Mediterranean regions, Renew. Sustain. Energy Rev. 14 (2010) 2772–2783. https://doi.org/10.1016/J.RSER.2010.07.021.

[80] C.E. Andraka, Dish Stirling Advanced Latent Storage Feasibility, Energy Procedia. 49 (2014) 684–693. https://doi.org/10.1016/J.EGYPRO.2014.03.074.

[81] J. Coventry, C. Andraka, Dish systems for CSP, Sol. Energy. 152 (2017) 140–170. https://doi.org/10.1016/J.SOLENER.2017.02.056.

[82] K. Liang, K. Xue, H. Zhang, H. Chen, J. Ni, Design and performance analysis of an annular fresnel solar concentrator, Energy. 210 (2020) 118594. https://doi.org/10.1016/J.ENERGY.2020.118594.

[83] K. Liang, H. Zhang, H. Chen, D. Gao, Y. Liu, Design and test of an annular fresnel solar concentrator to obtain a high-concentration solar energy flux, Energy. 214 (2021) 118947. https://doi.org/10.1016/J.ENERGY.2020.118947.

[84] C. Chen, K. Liang, J. Huang, S. He, H. Zhang, H. Chen, Experimental analysis of a solar interfacial evaporation under high power concentrator, Energy. 295 (2024) 131064. https://doi.org/10.1016/J.ENERGY.2024.131064.

[85] S. Abbas, Y. Yuan, A. Hassan, J. Zhou, A. Ahmed, L. Yang, E. Bisengimana, Effect of the concentration ratio on the thermal performance of a conical cavity tube receiver for a solar parabolic dish concentrator system, Appl. Therm. Eng. 227 (2023) 120403. https://doi.org/10.1016/J.APPLTHERMALENG.2023.120403.

[86] H. Zhang, N. Wang, K. Liang, Y. Liu, H. Chen, Research on the Performance of Solar Aided Power Generation System Based on Annular Fresnel Solar Concentrator, Energies 2021, Vol. 14, Page 1579. 14 (2021) 1579. https://doi.org/10.3390/EN14061579.

[87] E. González-Mora, M.D. Durán-García, Assessing parabolic trough collectors and linear Fresnel reflectors direct steam generation solar power plants in Northwest México, Renew. Energy. 228 (2024) 120375. https://doi.org/10.1016/J.RENENE.2024.120375.