Literature review of potential materials for the construction of an alternative flat-plate solar collector

Revisão bibliográfica de potenciais materiais para construção de colector solar plano alternativo

Revisión bibliográfica de materiales potenciales para la construcción de un colector solar plano alternativo

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Abstract
Through systematic review method the article presents the potential of existing solar energy in Mozambique for use in water heating with the integration of thermal energy storage systems that are currently being investigated. It emphasizes the need for affordable materials in building solar collectors for Mozambique’s homes, leveraging the country’s solar potential to reduce electricity consumption and environmental impact for sustainable development. It explores current research on thermal energy storage systems for solar water heating and reviews alternative materials for solar collectors based on their properties, cost, and availability. The importance of thermal energy storage in solar collectors for efficiency and load balancing is highlighted., it discusses and list the potential alternative materials for the construction of flat plate solar thermal collectors from roofing material, frame, absorber, pipes, and heat storage material according to their thermophysical properties, costs, and availability in the Mozambican market in the context of industrialization.
Keywords: Thermal energy storage; Solar energy utilization; Renewable energy sources; Flat solar collector.

Resumo
Através do método de revisão sistemática o artigo apresenta o potencial da energia solar existente em Moçambique para uso no aquecimento de água com a integração de sistemas de armazenamento de energia térmica que estão sendo investigados atualmente. Enfatiza a necessidade de materiais acessíveis na construção de coletores solares para as casas de Moçambique, aproveitando o potencial solar do país para reduzir o consumo de eletricidade e o impacto ambiental para o desenvolvimento sustentável. Ele explora a pesquisa atual sobre sistemas de armazenamento de energia térmica para aquecimento solar de água e revisa materiais alternativos para coletores solares com base em suas propriedades, custo e disponibilidade. Destaca-se a importância do armazenamento de energia térmica em coletores solares para eficiência e balanceamento de carga., discute e lista os materiais alternativos potenciais para a construção de coletores solares térmicos de placa plana a partir de material de cobertura, estrutura, absorvedor, tubulações e material de armazenamento de calor de acordo com suas propriedades termofísicas, custos e disponibilidade no mercado moçambicano no contexto da industrialização.
Palavras-chave: Armazenamento de energia térmica; Utilização de energia solar; Fontes renováveis de energia; Colector solar plano.

Resumen
Esta revisión de la literatura habla sobre las energías nuevas y renovables para el desarrollo sostenible. Aborda la necesidad de identificar materiales alternativos asequibles para la construcción de colectores solares planos para su uso en hogares en áreas rurales y urbanas. Investiga el potencial de la energía solar existente en Mozambique para su uso en el calentamiento de agua con la integración de sistemas de almacenamiento de energía térmica que se están investigando actualmente. El estudio destaca la necesidad del aprovechamiento de la radiación solar para el calentamiento del agua con el fin de reducir el consumo eléctrico y reducir los impactos ambientales mediante el aprovechamiento intensivo de la biomasa leñosa. A través del método exploratorio, se discute el potencial de materiales alternativos para la construcción de colectores solares térmicos de placa plana a partir de material para techos, estructura, absorbente, tuberías y material de almacenamiento de calor. La revisión presenta los puntos a considerar en la elección de materiales alternativos de acuerdo con sus propiedades termofílicas, costos y disponibilidad en el mercado mozambiqueño en el contexto de la industrialización.
Palabras clave: Almacenamiento de energía térmica; Uso de energía solar; Fuentes de energía renovables; Colector solar plano.

1. Introduction

The development of the nations is accompanied by energy demand, both for domestic and industrial use. However, there are limitations of physical structures for the supply of electricity during peak periods, it is more evident when the energy supply company in Mozambique seeks ways to respond to demand, injecting diverse sources and forms of energy into the electricity grid at all costs. The electricity supply company (EDM) rehabilitated the Mavuzi and Chicamba hydroelectric plants to cope with the growth in energy demand in Mozambique, specifically in the central region (Chichango, et, al.., 2021). However, the country is endowed with renewable energy sources, even though they are not fully exploited. For instance, the solar potential is significant, with an additional 1700 – 2100 W kWh/m² of global horizontal irradiation throughout the year (Cristóvão et al., 2021; Chichango & Cristóvão, 2021).

Despite the high potential of renewable energy resources in the country, the energy matrix has a higher rate of exploitation only of hydropower and biomass. The hydro potential in operation is 2185 MW out of the total 18.6 GW available. This energy is harnessed and converted into electricity, which is then utilized for various purposes such as powering industries, homes, and hospitals. While the potential of biomass energy recorded is 2GW, in which an exploitation rate is above 50%, this energy is harness in the form of cogeneration electricity in industries, and widely in the form of thermal energy in households for the conditioning food and heating sanitary water in more than 80% of the population living in rural and urban areas (Ministry of Energy, 2015; Cristóvão, et al., 2021).

The intensive use of the biomass resource is not ecologically sustainable, due to the environmental damage that logging has created for the ecosystem and the vulnerability to climate change that may resulting in sever cyclone registered recently in Mozambique and around the world (Meque et al., 2022). The UN precepts in the 2030 agenda call for the promotion, in #7, of clean and affordable energy, as well as, in #13, urgent decision-making to combat climate change. The intensive use of firewood and charcoal is a step backwards in the fight against climate change. Hence, there is a need to promote new sources of renewable energy in the Mozambican energy matrix. (UN, 2023; Chichango, et al., 2023).

Though, the Government of Mozambique launched the "Energy for All" program coordinated by the Ministry of Mining Resources and Energy (MIREME) funded by the World Bank Since 2020, the program has been reducing the level of access to electricity in the districts. The project aims to achieve 100% access to energy for all Mozambicans by 2030 (Chichango & Cristóvão, 2021). However, the utilization of solar energy has been for electricity generation. This electricity is subsequently converted into thermal energy for water heating. This process results in conversion losses and leads to excessive energy consumption during periods of high demand.

According to Alghoul et al., (2005), the technology of using solar radiation to heat water in homes has been investigated since the 1940s. Currently, there are several technologies for harnessing solar radiation for water heating, with China having the largest about 69.9% of the installed potential in the world (Chichango & Cristóvão, 2021). For the use of solar energy, it is not enough to have the availability of solar radiation, for the benefit it is necessary to invest in knowledge about the sector and to have financing. This intervention must be joint and with the political support of the government. The hot water is demanded in hospitals, hotels, industries and in collective and individual homes, for washing clothes, dishes, cooking, and bathing (Arthur, et, al., 2015).

Although the industries of researching and producing water heating solar collectors have grown in the world, in Mozambique there are still very few producers of these devices, according to Weiss & Dur, (2019) by the end of 2018, the country had an installed capacity and operational only of 2 MWth. Many users resort to importation, the weak supply drives the increase in the price of the systems, combined with no incentive, and the lack of clear policies on these devices, this has discouraged society from acquiring and using collectors in homes (Chichango & Cristóvão, 2021; Arthur, et, al., 2015).

Herewith, the present study expects to attend the first specific goal of the overall project of the PhD thesis in energy and environment (In FNCM/PU), which aims at designing of alternative solar systems for water heating in residences focusing on analysinganalyzing the efficiency and sustainable cost. To this end, the present research is concerned first with the literature review of potential materials for the construction of an alternative flat-plate solar collector.

The solar energy

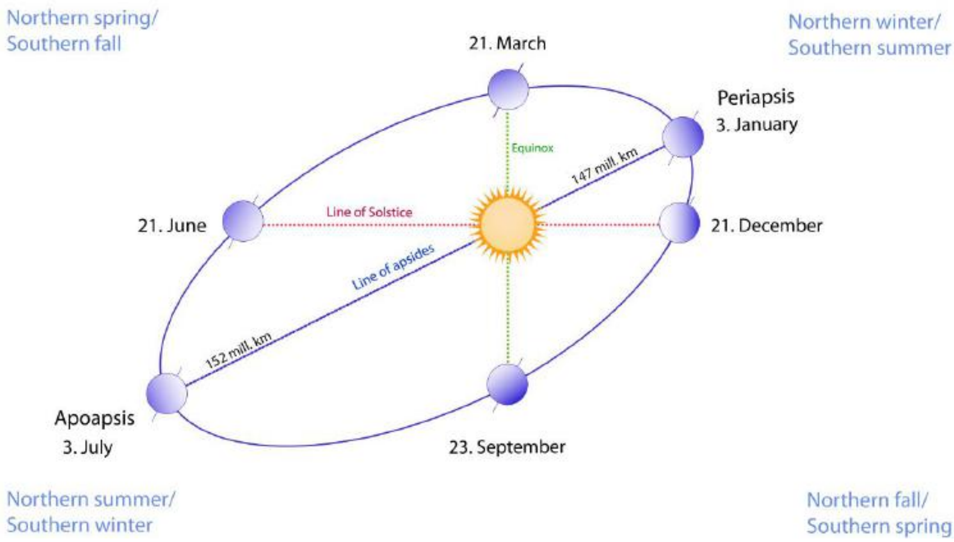
Solar energy is from solar radiation, which is on average 1.5 x 10^{11} meters from Earth. This sphere of very hot gaseous matter has a blackbody temperature of 5777 k, which varies in its central region from 8 x 10^6 to 40 x 10^6 k. According to Duffie and Beckman (2013), the sun is a reactor for continuous gas fusion, this succession of radioactive processes occurs with emissions, absorption and reradiation. The average radiation density outside the Earth's atmosphere is 1367 W/m^2 with an error of ± 1% in the range of 0.3 to 0.3µm of the wavelength.

Due to relative movement of the sun based on fixed earth system, to harness the solar energy with efficiency, knowledge is required about the concepts the angular variation of solar radiation along the day and year. This will allow the positioning of the solar collector for greater absorption of solar radiation. The direction of the radiation has distinct characteristics of the set of angles that determine the angle of incidence of the radiation on the Earth's surface. The common angle more analyzed is the beam radiation - the radiation with no scattering by the atmosphere, while the diffuse radiation, as it was changed by scattering by the atmosphere, has no specific direction. To estimate radiation in certain surface, the mathematic formulas and graphics presented by Duffie and& Beckman (2013)), and others, can calculate the solar time, direction, and the ratio of the beam radiation on a horizontal surface anytime and anywhere.

However, since solar radiation and environmental conditions are different throughout the world, FPSCs cannot be considered one-size-fits-all systems. Therefore, FPSCs must be properly designed for use at a specific location.

In addition, to the distortion of direct radiation by the atmosphere, variation in the distance between the sun and the earth throughout the year, it causes variation of the energy emitted by the sun becoming more greater intensity in one epoch than another. These variations are marked by two very distinct epochs of the year, summer and winter, the beginning of each epoch is marked by solstice and equinox as shown in Figure 1. According to Wojcicki, (2015) FPSCs must not considered one-size-fits-all systems, it is, “FPSCs must be properly designed for use at a specific location”.

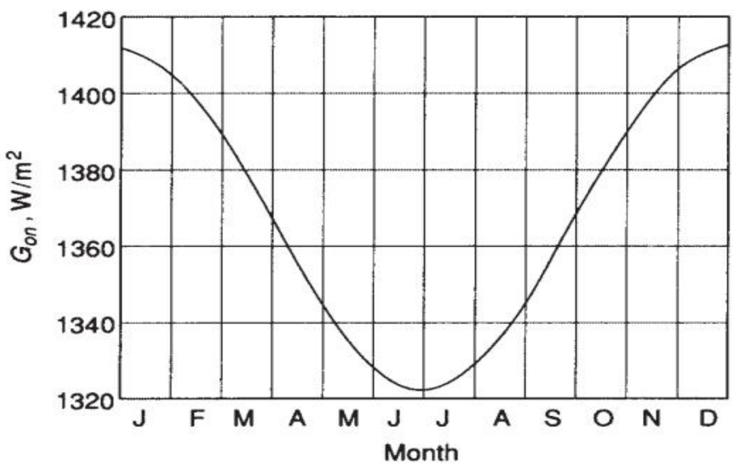
Figure 1 - Variation in the distance of the sun and the earth marking different epochs throughout the year.



Source: Universe today (2013).

In Figure 1, the epochs are contrary in the hemispheres northern and southern separated by the equator. In December the sun is closer than in July. The global radiance corresponding to the southern hemisphere is illustrated in Figure 2.

Figure 2 - Variation of the solar global irradiance during the year.



Source: Duffie and Beckman (2013).

In Figure 2, it is evident that in June and July the sun is more distant from the earth, so the solar irradiance in earth is minimum (winter), and in January and December the solar sphere is closer to the earth, consequently the global radiation is more intensive in this epoch (summer). For solar energy analyses, it is important to be done in both epochs for trustable results. The drawback of solar energy is the intermittence, the beam radiation often are being scattered by the atmosphere reaching earth surface disorientated with weak energy intensity.

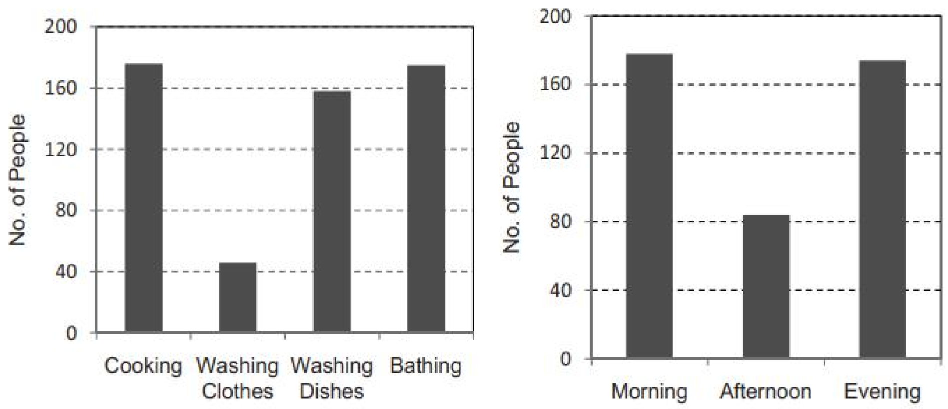
The consumption of electricity for water heating in households accounts for about 40% of the total energy consumed, this percentage may increase in winter. As a strategy adopted by other countries to overcome the use of electricity for water heating, direct radiation from solar energy is used through technologies to convert it into thermal energy (Chichango & Cristóvão, 2021; Arthur et, al., 2015).

However, these solutions require accessible technology and local labourlabor knowhow in this field. In another hand the limitation is in cost of the device, Nowadays, many attempts around the world are being done to decreasing the flat-plate collector’s final cost. Some researchers are focus on developing solutions using alternative material substituting metal parts for commodity plastics and the use of materials for heat storage up to the demand period (Zheng, et, al.., 2024).

Hot water application

The hot water generated by domestic Flat Plate Solar Collectors (FPSCs) is commonly used for: Space Heating: Enhancing the warmth of living spaces. Swimming Pools: Heating water for comfortable swimming. Industrial Preheating: Preheating fluids in various industrial, processes Domestic Hot Water: Supplying hot water for showers, washing dishes, and other household needs. Figure 3 shows an example of the domestic application and the period that required hot water in the household.

Figure 3 - Application and period of hot water demand in households.



Source: Ogueke et al. (2009).

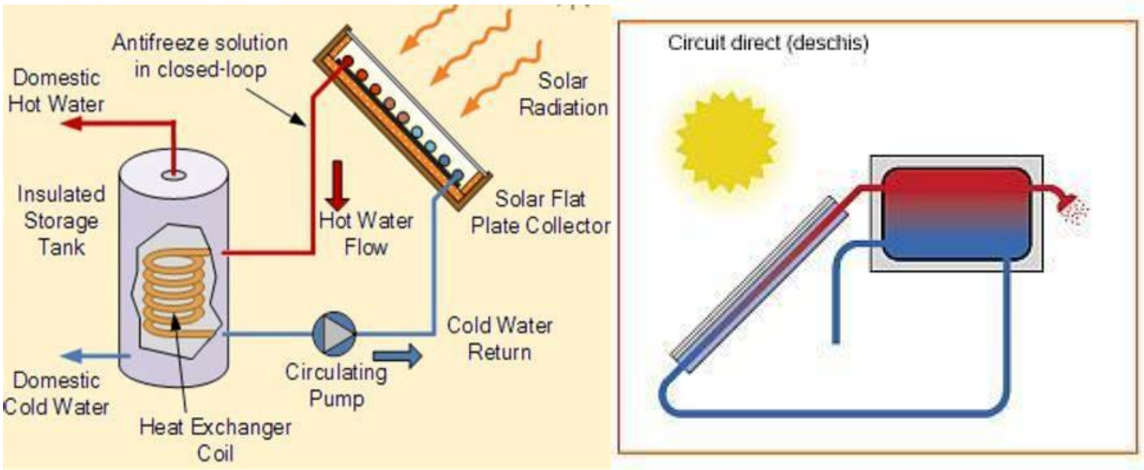
Figure 3 shows that cooking and bathing require more hot water. Morning and evening are period of hi demand than afternoon. This research where carried out by Ogueke and team in south Africa (2009).

Solar water heating systems

The solar water heat systems can be grouped in two operating types: active and passive systems. The difference between the systems is in the form of energy transfer to water and the addition energy required for operation. Active systems use heat-transfer fluids, electric pumps, valves, and some electric equipment in the circuit of water circulation control. As a result, they require additional energy for the operation of these electronic devices.

The electric pumps are used to circulate water from colector to storage tank in direct systems, while in indirect systems the pumps force de circulation of the operating fluid between solar collector and heat exchanger to transfer heat to water for use. The heat exchanger sometimes is the storage tank as shown in Figure 4. The active systems are more complex than passive, and they advantages is the gain of efficiency 35 – 85% higher than passive systems (Sadhishkumar & Balusamy, 2014). The indirect heating, its more applicable for regions with low temperatures in winter, due to antifreeze the water doesn’t freeze.

Figure 4 - Active and passive solar heat systems.

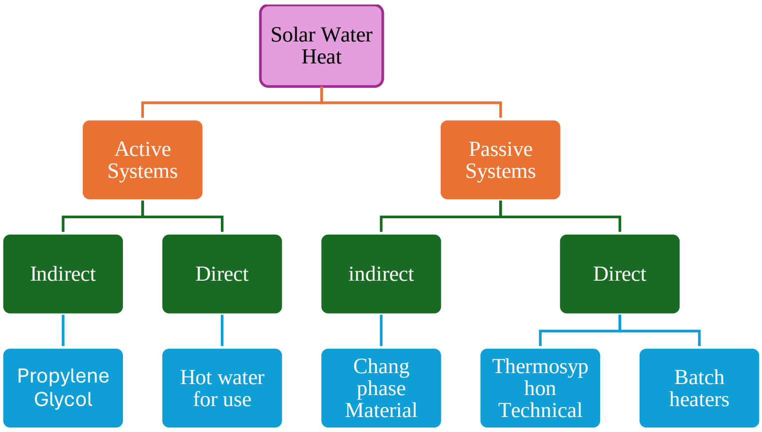


Source: University of California Natural Reserve System, UCSB (2024) and Variava and Bhavsar, (2017).

In the Figure 4, the active solar water heating system (on left) involves many liquid recirculation and control devices, making it more complex for domestic use. On the other hand, the passive system is simpler (on right), it does not require any additional energy. But the great disadvantage of this system it is that the storage tank must be locate above the solar collector and it operates according to natural convection heat exchange standards. According to Evangelisti et al., (2019), these systems are mainly used in individual households, where the hot water temperature is in the range of 40 to 80ºC.

The active technology can operate as direct and indirect heater, the passive technology is more applicable as direct heating using thermosiphon and batch heaters techniques. The classification of water heating systems can be summarized in the diagram in Figure 5 below.

Figure 5 - Simplified Scheme of types of solar water heating systems.



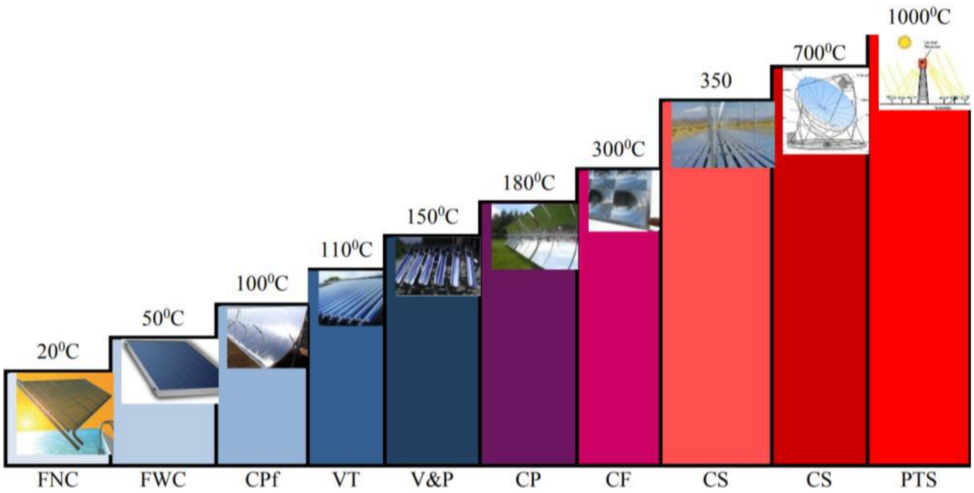
Sources: Authors.

For areas with lack of energy infrastructures, especially in rural areas, the thermosyphon technical is more advised as shown in Figure 5, in this, the water circulates induced by the variance in density between hot and freezing water. This is the object of study in this research, more details approach in next sections. In the passive system, it is rarely used – if indirect, when this is the case, the material used is a phase change by heating the material until it reaches the latent heat of vaporization.

Types of Solar collector

The use of solar energy begins with the absorption and concentration of radiation into internal energy by solar collectors. After absorbing the solar radiation, solar collector converts it into heat and transfers it to the working fluid in the indirect systems, and to the water used in the direct systems, as already mentioned in the previous section. There are different solar collector systems, they differ in technology, utility, and range of operating temperatures. According to Chichango and Cristóvão (2021), the collectors can operate from 20ºC to the range of 1000ºC, hot temperatures solar collectors are used in direct air heating for industry use or electric energy production. The Figure 6 presents the different operating conditions of the solar collectors.

Figure 6 - Operating temperatures of different thermal energy technologies.



Legend: FNC- Flat not Covered; FWC – Flat with Cover; CPf – Cylinder parabolic fixed; VT – Vacuum tube; V&P – Vacuum and Parabolic; CP – Cylinder parabolic; CF – Concentrated Fresnel; CS – Concentrated Stirling; CTS – Power Tower System

Source: Chichango and Cristóvão (2021).

In Figure 6, it is notable the solar collectors for domestic use are in the range of 20-110ºC from FNC up to VT, the others are more used in hospitals, hotels, and industries.

The most used collectors for water heating in households can be classified into covered and uncovered flat-plate collectors and evacuated tube collectors. Flat-plate collectors have the disadvantage of needing to adjust the angle with respect to the angular variations of the sun, while evacuated tube manifolds, as they are cylindrical, can receive direct radiation from the sun in an angular range of 90 degrees per day, and this gives a higher efficiency to evacuated tube collectors, but for tropical areas where temperatures are higher, flat-plate collectors are more recommended. Both collectors are presented in Figure 7 below.

Figure 7 - Flat-plate and Evacuated tube water heat systems.

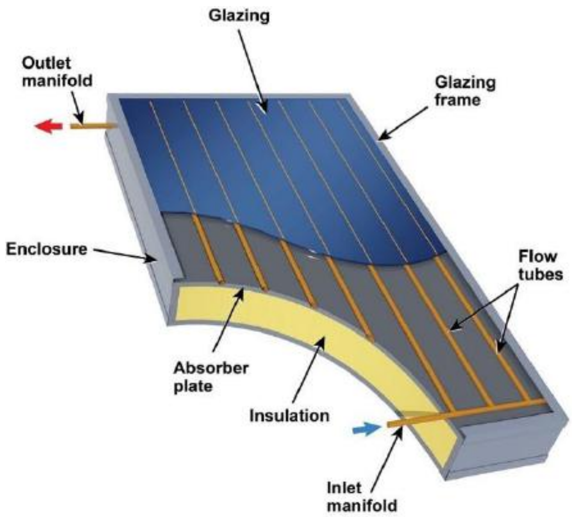
Source: Modernize (February 12th, 2024).

In Figure 7, the flat-plate solar colector on the left is glassed type. It can receive the maximum radiation in the midday (when the sun is in vertical plane), the evacuated tube is on the right, due to its configuration, it can collect rays in angle of 90 degree. However, considering the water temperature required in households, and the affordable devices cost for communities, the flat-plate solar collector is recommended. In addition, this system can be built from different alternative materials. In this case, as the authors in this research are looking for alternative materials for construction of solar water heater for homes, the focus is on flat-plate collectors.

In terms of Solar flat-plane collector – composition. The solar flat-plate collectors can be glazed or unglazed (covered or uncovered) as illustrated by the first device in Figure 7. The collector shown in Figure 8 shows the location of each element on the device.:

1. Frame – external structure containing all parts of device.
2. Cover in covered systems - Usually transparent glasses or other diathermal material to minimize heat loses.
3. Inlet manifold, flow tubes and outlet manifold tubes.
4. Absorber plate- absorb and retain heat.
5. Insulation material – to prevent heat loss from collector to ambient.

Figure 8 - Composition of the solar flat-plate collector.



Source: Pacific Northwest National Laboratory (February 16th, 2014) available on www.pnnl.gov/projects.

The diagram in Figure 8, illustrates a simple flat-plate solar colector glazed, its notable insulation and the absorber plate play the crucial role of heat transmission to water through flow tubes.

2. Methodology

The present review is part of the PhD program internship going on in the thermodynamic laboratory of mechanical engineering in Engineering Faculty of the Eduardo Mondlane University in Maputo. In this practicum, potential materials alternative to produce a low-cost flat-plate solar collector will be identified. This review integrates the first specific goal of the Thesis in progress of constructing an alternative flat-plate solar collector using alternative materials, and available locally.

Therefore, the study is conducted by an exploratory research method, considering that it is applied when the objective is to become more familiar with the study. The technical procedures consist of a literature review, interviews with experts in the field and consulting published documents, books, and other articles available on google scholar, and journals of par reviewed. One of the advantages of the exploratory method is the freedom to choose the specific technics. In this, each of the 5 influential components in performance of the flat-plate solar collector was particularly analysed in terms of: its function, economic viability and thermophysical proprieties. The lifetime of the material was also taken in account in analyses.

The economic viability of the components is linked to accessibility of the raw materialThe study is a systematic review of the literature about alternative materials for solar collectors for water heating in homes, in which it seeks to bring together different materials published in different scientific journals and in practical experiences (Medyk et al, 2022; Galvão et al.,2019 and Rother, (2007).). The hypothesis is that conventional materials such as aluminum and copper increase the cost of operating solar collector production, making them more expensive for most of the population living in poor countries. Thus, bringing collectors manufactured with alternative materials, whose thermophysical properties are acceptable for application in this device, can increase the interest and demand for the use of the devices, thus promoting the use of renewable energies.

Within the scope of the research question, what are the construction materials for flat-plane solar colector can reduce the overall of devices, especially for unindustrialized countries, likein Mozambique, and the performance of the apparatus is associated to thermophysical proprieties of the components. This question will conduct the research as required in systematic literature reviews mentioned by Galvão et al. (2019), Rother (2007). The objective of this research is to bring together different alternative materials and discuss their employability in solar collectors from the point of view of cost-benefit and durability.

This action is based on the need for the use of solar collectors in massive, for the use of solar energy and diversification of the energy matrix. As a result, there will be a reduction in the consumption of non-renewable energy sources with environmental impacts.

In addition, it will reduce deforestation due to the search for woody biomass. The research includes the evaluation of the employability of these materials in the Mozambican context, looking at the level of industrialization of the country, as well as the availability of raw materials and the financial capacity to acquire these materials.

The solar collector has fundamental components that influence the performance and cost of production. There are five components to analyses applicability and lifespan. Thus, to conduct the research, some hypotheses were carried outmade for each component: according to the method review in use (Rother, 2007):

1. For cover material: The thickness and material of the cover for flat-plate collector influences the thermal load transferred to the collector. Knowing the relationship between thickness and heat transfer capacity, then is then possible to choose the best material and ideal thickness to maximize the transferred thermal load.

2. Frame material: The frame of the flat-plate solar collector is the border surrounding the device this, and the cover, they protect the device from outside climate, so the frame material for flat-plate collector must be resistant for stress deformation, and for outdoor climate (solar radiation, raining wind etc.) sometimes may need additional coating to last long.

3. For absorber material: The absorber plate, component which transfers the heat from the cover to the water flow pipes, should be from material with considerable absorption properties in the visible solar spectrum, good heat transmission to water, low emissivity, and reflectance.

4. Flow water pipes: The water flow tubes in collector, they receive the heat from the absorber plate and transfer to the water, they work in relative elevated temperature then, they must have considerable thermal resistance and high capacity of heat transfer to water.

5. Thermal energy storage: Due to intermittent of solar radiation, considering hot water in homes is more demanded at night period, heat conservation mechanism is needed. The TES must have high capacity of heat storage. So, latent or sensible heat storage system would increase the performance of the device delivering hot water in the time needed.

The study was based material to conception solar collector to provide hot water in single-family homes. The temperature capacity of the device is assumed in range of 50 -80 ºC, according to the average of hot water temperature demanded on single houses.

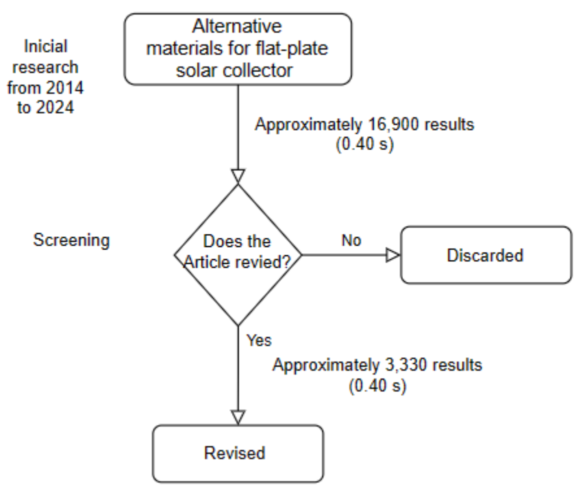
The sources for this review will be searched on the google school platform, the keywords will be “alternative materials for hot water using flat-plate solar collector” adding each of the components investigated. To filter the information, reviewed and recent articles from 2014 to 2024 will be considered. For the eligibility will be the number of citation and the trust of peer-reviewed articles.

3. Results and Discussion

The topic has been widely investigated by researchers from almost all corners of the world, with generic objectives of finding more adequate, effective, and efficient ways to capture solar radiation and convert it into useful energy, which is clean and abundant, to reduce energy dependence, the use of non-renewable sources, the reduction of environmental impacts, in favor of sustainable development predicated by the emergence of technology and population growth.

After the documents analysed, flat plate solar collectors and evacuated tube collectors are recommended for domestic use due to the low temperature levels they can offer. Flat plate collectors are more flexible to adaptations to meet local needs, they can be built with cheaper materials when passive (Akbar, et al., 2022; Zheng, et al., 2024). Figure 9 illustrates the sample flowchart of the articles with the related thematic from up to 2024.

Figure 9 - The decreased number of articles as filtering.



Source: Authors.

From 2014 to 2024, more than 16900 articles related to flat solar thermal collectors were published. Of that number, 3,330 articles were peer-reviewed. For the present study, in addition to this article, other articles related to parts of this discussion were listed. Table 1 presents the corpus summary of articles selected after filtering for the literature review on the topic in progress.

Table 1 - Corpus of articles selected after filtering.

ID	Title	Author	Publication year	Keywords	Summary
01	Thermal energy storage techniques	Adeyanju	2015	Energy storage, Techniques, Water storage, Packed-bed storage, Phase change storage	The study reviews energy storage techniques. Water systems have volume and corrosion issues. Packed-bed storage may increase in cost. Phase change systems eliminate large volumes but lose energy storage characteristics over time
02	CFD-thermal analysis of flat plate solar collector for different temperature variations	Akbar et al.	2022	Solar collectors, CFD, Thermal, Heat transfer	This work uses FEA to evaluate solar collector performance, predict output temperatures, and analyze material-induced deformation
03	Review of materials for solar thermal collectors	Alghoul et al.	2005	Physical properties of materials; Polymers; Heat transfer; Solar collectors	This paper fulfils identified information about materials and heat transfer properties of materials and manufacturing challenges of these three solar thermal collectors.
04	Comparison study of solar flat plate collector with two different absorber materials	Amrizal et al.	2017	solar collector, absorber plate, thermal performance	The study compares copper and aluminum absorbers in solar collectors, finding no significant performance difference, but aluminum offers cost advantages.
05	Potential application of solar water heaters for hot water production in Turkey	Benli	2016	Renewable sources; Solar water heaters; Galvanized sheet absorbers	Turkey's growing energy market is focusing on renewable sources, especially solar. The study compares solar water heaters and finds galvanized sheet absorbers most effective
06	Mozambique Solar Thermal Energy Technologies: Current Status and Future Trends	Chichango & Cristóvão	2021	Climate change, electricity, thermal energy, solar collector, radiation	Mozambique's growing economy and population increase power needs. Despite abundant natural energy, electricity access is challenging. Solar energy, particularly thermal, offers potential solutions.
07	Phase change materials in solar domestic hot water systems: A review	Douvi et al.	2021	Latent heat storage; Domestic hot water; Review Solar	Review of solar energy storage using phase change materials for hot water production. Challenges include material selection, water flow rate optimization, and improving thermal conductivity."
08	Latest advances on solar thermal collectors: A comprehensive review	Evangelisti et al.	2019	Renewable Energy Focus; Solar Thermal Collectors; Standards and Performance; Technological Developments.	This review explains how every functional element is fundamental for improving the efficiency of these devices. Innovations related to absorbers and heat transfer fluids are the most investigated in literature
09	Glass and coatings on glass for solar applications.	Ganjoo et al.	2019	Glass, Coatings on Glass for Solar Applications	The chapter discusses glass's role in solar power, its evolution, uses, and challenges in solar applications.
10	Solar energy materials for glazing technologies	Gorgoli & Karam	2016	Glazing Materials; Innovative Materials; Energy Savings; Glazing Integrated Photovoltaics.	The article reviews the solar energy Innovative materials in glazing categories, and concluded that they can optimize solar interaction, maximize energy savings, and achieve low thermal conductivity.
11	Review on solar collector systems integrated with phase-change material thermal storage technology and their residential applications	Liu et al.	2021	Solar phase-change energy storage systems; Microencapsulated phase-change materials (PCMs); Solar collector system efficiency	The article reviews solar phase-change energy storage systems, highlighting efficiency improvements through microencapsulated PCMs and optimal system configurations.

12	Performance enhancement analysis of the flat plate collectors: a comprehensive review	Sakhae & Valipo	2019	Flat Plate Collectors (FPCs); Thermal Efficiency; Design Parameters: Nanofluid.	This paper presents an overview on the different techniques that are employed to enhance the efficiency of flat late collectors. Effect of using nanofluids as heat transfer fluid.
13	Flat Plate Solar Thermal Collectors—A Review	Sarma et al.	2021	Solar thermal flat plate collectors (STFPC); Front heat loss; Collector efficiency. Solar energy; Solar collector.	This paper reviews Solar Thermal Flat Plate Collectors (FPC), their applications, and methods to improve their thermal performance by reducing various losses. It also discusses future research directions.
14	Conductive and convective heat transfer augmentation in flat plate solar collector from energy, economic and environmental perspectives — a comprehensive review	Sharma et al.	2022	Flat plate solar collector; Absorber plate; Absorber tube; Nanofuids; Conduction; Convection	This paper reviews methods to enhance conductive and convective heat transfer in Flat Plate Solar Collectors (FPSC), including absorber configurations, nanofluids, and combined techniques. It also identifies research gaps and future directions.
15	A review on the simulation/CFD based studies on the thermal augmentation of flat plate solar collectors	Thakur et al.	2021	Flat Plate Solar Collectors; Computational Fluid Dynamics; Thermal Performance; Simulation Models	FPSCs, widely used for heating, can be optimized for efficiency and thermal performance using various methodologies, materials, and design modifications.
16	The application of the Typical Day Concept in flat plate solar collector models	Wojcicki	2015	absorber plate; heat transfer coefficient	Flat-plate solar collectors use solar radiation to heat fluid. Designing for specific locations and applying the Typical Day Concept can improve model accuracy and efficiency.

Source: Authors.

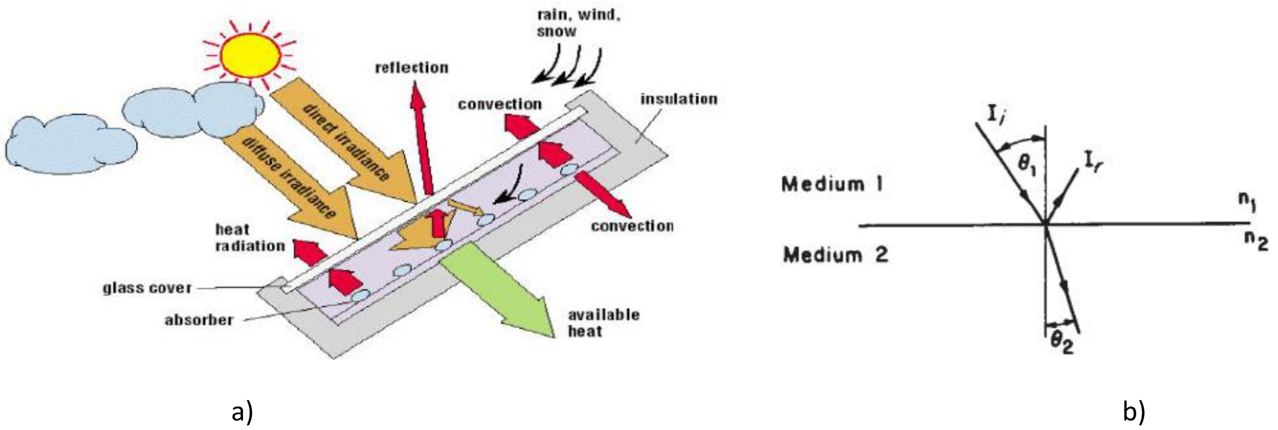
From the research in google and the sample presented in the table is notable many authors are in distinct stages, and are investigating in different scopes, many are investigating the effective ways to heat storage and the innovative efficient material. This shows, in addition to the relevance of this thematic, the gap that still exists for the efficient development of solar collectors, considering the differences that exist in the needs of each place where it is designed.

The discussions presented above are some examples of articles whose results are promising in terms of continuity in the identification of points that, in general, lack the operating costs of solar collectors, opening the possibility of employing new materials according to the availability of materials. Solar thermal collectors are devices that are more likely to be produced with different alternative materials. To demonstrate this discussion, the probable materials to be used are presented for each component of the solar collector, and them functions as well as the advantages and disadvantages.

Cover glass material

The performance of a solar collector is estimated as a function of the transmission, reflection, and absorption of solar radiation from its components. The properties of the cover glass in flat-plate collectors, where solar radiation falls, are fundamental in the formulation of the equations of the overall performance of the collector, especially for phenomena of transmittance, reflectance, and absorption of incoming radiation. Glass cover’s coating, thickness, transmittance, and emissivity affect FPSCs thermal performance. Insulating materials and air gap management can minimize heat loss, enhancing efficiency (Thakur et al. 2021). Hence, theThe variables such as thickness (t), refractive index (n) and extinction coefficient (k) of the material are of paramount importance.

Figure 10 - Incident radiation on cover and transmittance in different mediums.



Source: VQuaschning, (2004) and Duffie and Beckman, (2013).

Thickness (t) of the cover glass can enhance insulation and reduce heat loss from the collector. However, an excessively thick material may reduce the amount of solar radiation transmitted to the absorber, affecting overall efficiency. In addition, cover transparency is fundamental, heating savings can be achieved by integrating innovative transparent components and selective coatings (Gorgoli & Karam, 2016). According to the Tripathi et al., (2018) transparent cover must act as a “heat trap” to the solar radiation allowing entrance but not out.

The refractive index (n) of the cover medium determines how much light is bent or refracted when it enters the material. Higher refractive indices can lead to better light trapping within the collector, increasing absorption. However, if the refractive index is too high, total internal reflection may occur, preventing light from escaping the material. The Extinction Coefficient (k) represents the absorption and scattering of light within the material. A higher k value indicates greater absorption of solar radiation. Optimal k values balance absorption with efficient transmission through the material. (QAiST- EN 12975; ISO 9806:2017; Alghoul, et al.., 2005).

Convectional glazing material for FPC is tempered low-iron glass, as presented in commercial FPC, but alternatively is applied, non-tempered glass, and polymer resistant to UV, fiberglass, and reinforced plastic with specific coating. According to Alghoul et al., (2005), the cost premium for low-iron glass is smaller than its increase in efficiency. For Zeng et al.., (2024), although polymer systems could reduce the performance and lifetime, the achieved reduction of weight and cost makes this solution attractive in some applications. In polymers, Rojas, (2021) advises the use of honeycomb polycarbonate, as it has two layers, an inner layer of air, as it is good insulator, and lightweight, as it has good resistance to shocks.

Therefore, selecting cover glass materials with appropriate thickness, refractive index, and extinction coefficient is crucial for maximizing solar collector efficiency. The Table 2 below presents some material and their description, used as cover in solar flat-plane collector.

Table 2 - Properties of material used as solar collector cover.

Element/Material	Principal Description	Transmittance in visible spectrum	Reflectance	Melting point (ºC)
Glasses: 1. Tempered uncoated and glass (low iron) 2. Non tempered and Coated glass	High transmittance, elevated temperature capability, low transmittance in the long IR, strong. Disadvantages: heavy, breakable, excessive cost.	80% <80%	7% >7%	1400 - 1500
Polymer: 1. Polycarbonate-corrugated pattern 2. Polycarbonate – Multiwall 3. Polycarbonate --- Rigid sheet 4. Rigid PVC sheet	Good transmittance, high impact resistance, good temperature capability (270F), light weight, low cost, good life, easy to cut, low transmittance in the long IR.	86% <86%	10% >10%	145 - 250

Source: Gary (2008).)

In the Table 2, the tampered glass, thin, low iron, and transparent has better proprieties, and for polycarbonates the multiwall ones may has lifetime and temperature capability, but not as good as glass. The glass requirements are anti-reflective surface treatments, transparent conductive coatings, However, maysome glasses can be used as alternative but need additional coating or additives to resist UV. Ganjoo (2019). Thus, in the current conditions of industrialization in Mozambique, it is convenient to used non-tempered glass to reduce cost.

For Mozambique conditions, common glass is more accessible than tempered, also than polymer resistant to UV, are also accessible and cheaper than honeycomb polymer sheet. Using non- tempered glasses thickness 0.4 to 5.0 per square meter can be reasonable for design.

Alternative material for frame

The external structure of a flat plate solar collector is composed of an edge that surrounds the device, it is known that this, and the cover, they protect the device from the external climate, for the choice of this material, it is necessary to observe the local climatic conditions, durability, and cost.

As an alternative to the aluminum used in commercial manifolds due to its lightness, resistance to corrosion, in alternative structures Stainless Steel can be applied, it is also corrosion resistant and durable, it is a more robust option, but it can also be more expensive.

The other emerging option is the use of fiberglass reinforced plastic (FRP). It is also a lightweight, resistant, and non-corrosive material, suitable for harsh environments. Engineering plastic materials such as polymers, polypropylene or polyethylene can be used. The plastics are lightweight, easy to shape, and sturdy. Another alternative is treated wood, for regions like Mozambique having a lot of wood, when it treated with chemicals can resist moisture and deterioration, it is a more natural and aesthetically pleasing option. If there is a balance between the accessibility of wood and the cost of treatment. Finally, recycled materials, such as recycled plastic, wood or recovered metal, can be used for a more sustainable approach if the economic feasibility analyses are satisfactory for all cases. The current discussion is in the decision between the choice of polymers (PVC) or wood in terms of environmental impacts and the useful life in the face of weathering that it may be subject to.

AbsorberMaterial for absorber plate

The absorber plate transfer heat to the water flowing in pipes rigidly connected to it. The propriety of the material of the absorber is to have high thermal conductivity, good connection with the materials of the flow pipes, and low UV reflection.

There is a lot of discussion about this device that is crucial in the transfer of heat to water.

The Table 3 presents some materials commonly used for absorbers plate. From the analyses carried out, the authors recommend that, in addition to comparing the thermophysical properties of the materials, there is a need to examine the cost-effective, especially the resistance the material degradation.

Table 3 - Density and heat specific to common materials used as absorber plate.

Element	*Density* ρ, $[\frac{kg}{m^3}]$	*Specific heat* c_p, $[\frac{J}{kg}.K]$	*Thermal Conditivy* k, $[\frac{W}{K.m}]$
Copper	8954	386	398
Steel	7833	465	45
Crown glass	2500	670	1.05
Mica	2883	880	0.71
Polyethylene	950	900 -1800	0.33
Aluminium	897	900	247

Source: Adapted from www.myengineeringtools.com/ accessed March 29th.

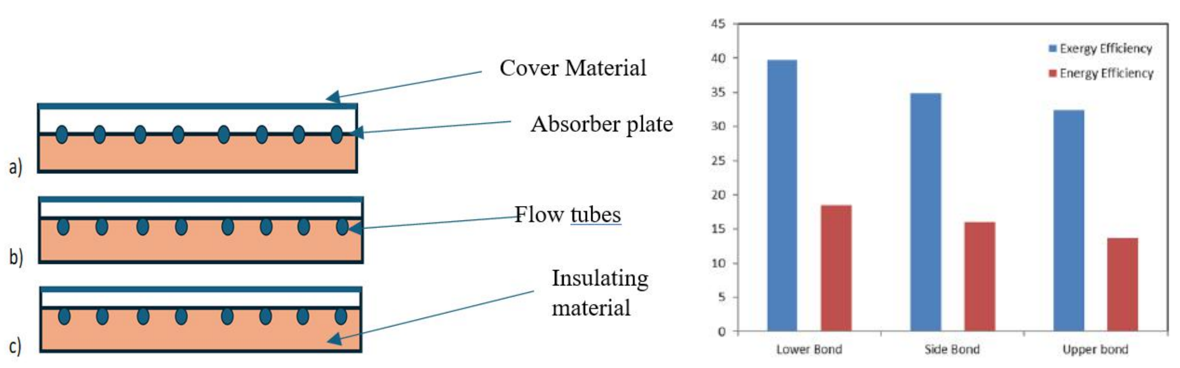
In the Table 3, copper needs less energy to vary its temperature and has a high thermal conductivity, it's still being therefore, the best material option for absorber, however it is a weighty and relatively more expensive material than other materials. The polymers have proven high potential low- cost material for absorber, but they have low thermal conductivity.

According to study from Amrizal, et al., (2017) where compared different absorber materials, copper, and aluminium, and concluded aluminum as viable alternative to copper, providing an advantage in terms of thermal performance and production costs, and due to its higher thermal conductivity value and lower material price and density. In addition, selective coating areis used to enhance the absorber plate.

The research of the Garg, (1986) explores the design and optimization of solar energy collectors, focusing on the absorber plate. It discusses the importance of material properties, including high thermal conductivity, good connection with flow pipes, and low UV reflection. The "Overview of Flat Plate Collectors" published on Fedkin (2024) explains how the absorber plate absorbs solar radiation and transfers heat to the fluid in the pipes. In this, presents diverse designs of flat-plate collector assembly mentioning the variety of methods of component attachment - thermal cement, solder, clips, clamps, brazing, mechanical pressure applicators. However, the document suggests considering the assembly method according to its cost of labourlabor and materials. Figure 11 present distinctive designs of joining absorber and the tubes.

The are distinctive designs of connections, Figure 11 presents three different connections between absorber plate and water tubes in a flat-plate solar collector.

Figure 11 - Performance comparison of the different joining between absorber plate and water tubes.



Source: Adapted in Duffie and Beckman (2013); and Sharma, et al. (2022).

The Sharma et, al., (2022) analyzed the "Conductive and Convective Heat Transfer Augmentation in Flat Plate Collectors", affirm the improper joining of the tube and the absorber plate, and the presence of air hugely impacts the conduction heat transfer process, and the joining between the tubes and the absorber plate must highly consider.

In addition, coating material a used to enhance the performance of the absorber plate. According to Bittar, (2013), selective absorber coatings are being used. These coatings are designed to maximize absorption of solar radiation while minimizing thermal losses. The selective coatings for solar collectors include:

Semiconductor/Metal Double Layer: This type of coating combines a semiconductor layer with a metal backing to absorb a wide spectrum of solar radiation while minimizing re-radiation of heat.

Metal Dielectric Interference Stacks: These are thin layers of metals and dielectrics that interfere with the solar spectrum to enhance absorption and reduce emissivity.

Graded Index Layers: These coatings have a gradient of refractive index that is engineered to capture more sunlight and convert it to heat.

Cermet Composite Multilayers: Cermet is composite materials made from ceramic and metal, which are used to create coatings that have high solar absorbance and low thermal emittance.

Paints: Special solar selective paints can be applied to absorber plates; they are easy to apply and cost-effective.

Naturally, for cost – effective solution in alternative solar collector will be used paints, they are available and accessible in Mozambique rural context.

Water flowMaterial for water tubes material

To choose material for water flow consider their ability to withstand the operating conditions of solar collectors and their effectiveness in transferring heat. For alternative material to cupper, which is the common material for this propose, in the Table 4 are listed other material with properties to be used as tubes.

Table 4 - Pipe Materials Used in Flat- plate Solar Collectors.

Material (and acronym)	Melting point (Celsius degrees)
Copper - CU	1083
Chlorinated Polyvinyl Chloride - CPVC	170 -200
Galvanized Steel	1370 - 1510
Polyvinyl chloride – PVC	177
Stainless Steel	1454 - 2650
Polyethylene - PE	110 - 115
Polycarbonate - PC	297

Source: Authors.

In Table 4, it is notable that the stainless-steel material has a higher melting point, meeting the requirements for water pipes in flat-plate solar collectors. However, further studies must be conducted to suggest its use, considering factors such as short-term degradation, cost, heavy flexibility, etc.

Fiberglass Reinforced Polymer (FRP) pipes, characterized by their lightweight, resistance, and non-corrosive properties, serve as a viable alternative to copper. Within the realm of engineering plastic materials, there exist various substitutes for polymer tubes, including polypropylene and polyethylene. These plastics are not only lightweight and easy to mold, but also resistant to pressure and moderate temperatures. Other types of polymer pipes, such as PVC or PEX plastic pipes are commonly utilized due to their flexibility, corrosion resistance, and suitability for hot water systems.

Shakaei and Valipour (2019) conducted a study on the improvement of thermal performance in flat plate collectors (FPCs). They proposed the incorporation of turbulators within FPCs and the use of nanofluids. The materials they discussed include discs, wire coils, twisted tapes, metal foams, and more. However, it is crucial to select the tube material that aligns with the absorber material to ensure optimal performance and durability in solar collectors. Here are seven considerations to consider:

1. Thermal Expansion Compatibility: The thermal expansion coefficients of the tube material and absorber material should be similar. This minimizes stress and prevents leaks or damage due to differential expansion and contraction during temperature changes.
2. Resistance to Corrosion: It is imperative that both the tube and absorber materials demonstrate a high degree of resistance to corrosion. Factors such as exposure to sunlight, moisture, and other environmental elements can instigate corrosion over time. Frequently selected materials, such as copper, aluminum, and stainless steel, are typically preferred due to their inherent resistance to corrosion.
3. Heat Transfer Efficiency: The tube material should efficiently transfer heat from the absorber to the working fluid (usually water or another heat transfer fluid). Materials with high thermal conductivity, such as copper, are preferred.
4. Methods of Joining: It is imperative to ensure rigid joining. The material of the tube should be conducive to forming secure connections with the absorber plate. Techniques such as welding or brazing may be employed. For example, if the absorber plate is composed of copper, the use of copper tubes can facilitate the process of rigid joining.
5. Cost and Availability: Consider the cost and availability of the tube material. Some materials may be more expensive or harder to find, affecting the overall system cost.
6. Operating Temperature Range: Solar collectors experience a wide range of temperatures, in stagnation situation. Ensure that the tube material can withstand extreme heat without compromising its integrity.
7. Longevity and Maintenance: Choose a material that offers longevity and requires minimal maintenance. Durability is crucial for the system's overall lifespan.

In summary, the choice of tube material should be a well-informed decision based on compatibility, performance, and practical considerations.

Material for thermal storage energy

Thermal energy storage (TES) in flat solar energy collectors enhances efficiency, balance the energy supply, allow to shift the load, and create grid independence. Storing thermal energy allows to shift the load. For instance, in residential applications, excess heat collected during the day can be used for space heating or hot water supply in the evening or early morning.

Tian and Zhao, (2013), they reviewed solar collectors and thermal energy storage systems. The researchers concluded the TES Reduce Heat Loss capturing sunlight and converting it into heat. Thermal energy storage allows for storing excess heat during sunny periods and releasing it when needed. It not only reduces convection losses from the absorber plate but also minimizes irradiation losses from the collector due to the greenhouse effect.

Wang, et al., (2020). The TES balancing Energy Supply, solar energy availability varies throughout the day and across seasons. By incorporating thermal storage, it is possible to balance the energy supply. Excess heat collected during peak sunlight hours can be stored for use during cloudy days or nighttime.

Farulla et al., (2020) discuss about the review focusing on thermochemical thermal energy storage systems and their application in power-to-heat processes, particularly in the context of renewable energy sources. the researchers Identified The energy storage as a critical component in power system design and operation, providing flexibility and linking power networks with heating/cooling demands. They recognize that thermochemical Systems is gaining attention for their superior performance over sensible and latent heat storage technologies, especially regarding storage time dynamics and energy density.

The TES can be grouped in tree types of systems with different parameters of heat capacity as shown in Table 5 bellow, and some of advantages of the TES Include additional flexibility, load management, power quality, continuous power supply, and better utilization of variable renewable energy sources, which are vital for increasing the commercial profitability of these systems. The challenges are the excessive costs associated with power-to-heat/thermochemical systems to enhance the technology readiness level. In table x the TES systems are grouped, and it is the thermophysical properties are presented.

Table 5 - Parameters of types of thermal energy storages systems.

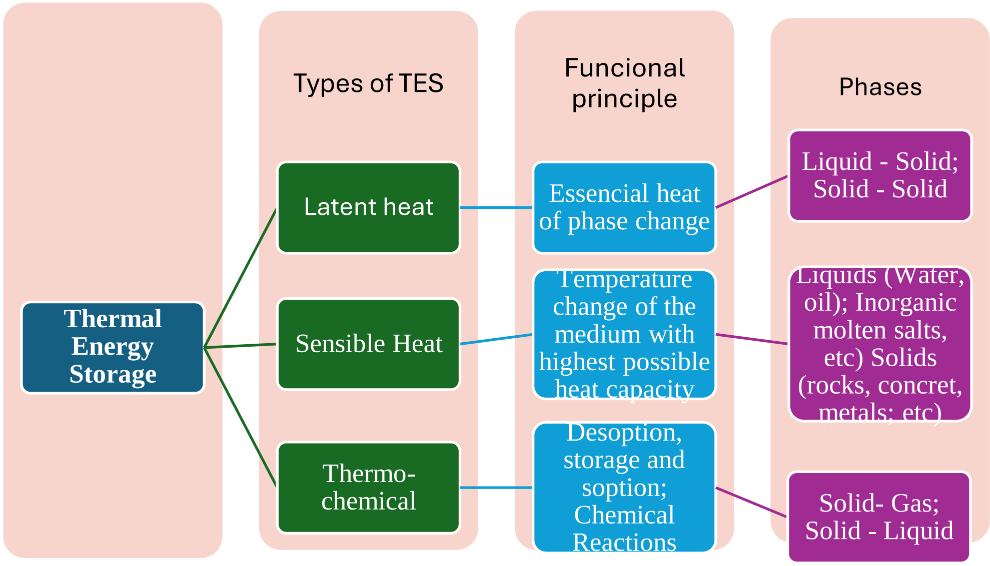
TES System	Capacity (kWh/t)	Power (MW)	Efficiency (%)	Storage Period	Cost (€/kWh)
Sensible	10–50	0.001–10.0	50–90	days/months	0.1–10
Latent	50–100	0.001–1.0	75–90	hours/months	10–50
Thermochemical	120–250	0.01–1.0	75–100	hours/days	8–100

Source: Farulla et al. (2020).

In the Table 5, the technology of the sensible TES differs in lengthy period than other, but the capacity of storage is fewer. Thermochemical has more capacity to store for short periods, hours, or days, and is more expensive system than others.

In terms of the operating principles of each system, the types of TES are in Figure 12, which presents, in addition to the principles of operation, the heat storage phases.

Figure 12 - Types of Thermal solar storage.



Source: Adapted from Adeyanju, (2015) and Farulla et al.., (2020).

The phase change material (PCM) occurs in the storage system with addition or removal of latent heat, while in other types of TES there is only heating of the medium or solid without phase change. In the thermochemical storage system, heat is stored when the chemical elements are separated, and is released when mixing or vice versa. The properties of liquid and solid medium for sensible heat storage are in Tables 6 and 7.

Table 6 - Properties of liquid used in Phase Change Material storage systems.

Medium	**Fluid Type**	**Temp. range** (^0C)	**Density** (kg/m^3)	**Heat capacity** ($J/kg.k$)	**Thermal Conductivity** ($W/m.k$)
Water	-	0 to 100	1000	4190	0.63 at 38 C
Dowtherms	oil	-10 to 315	867	2200	0.112 at 260
Theminol 66	oil	-9 to 343	750	2100	0.106 at 20C
Draw salt	Molten salt	220 to 540	1733	1550	0.57
Hitec	Molten salt	141 to 540	1680	1550	0.61
Engine	oil	Up to 160	888	1880	0.145
Lithium	Liquid salt	180 to 1300	510	4190	38.1
Sodium	Liquid salt	100 to 760	960	1300	67.5

Source: Adapted from Adeyanju, (2015).

In Table 6 the water is the medium more available and with higher heat capacity but, it has a low boiling temperature, thus limiting its ability to store more heat. Lithium has high heat capacity, higher abolition point compared to water, but it is more expensive. For sensible heat storage, the solid materials are in Table 7 below.

Table 7 - Properties of solid medium for sensible heat storage.

Medium	**Density** (kg/m^3)	**Specific heat** $(J/kg \cdot k)$	**Heat Capacity** $\rho c \cdot 10^{-6}(\frac{J}{m} \cdot k)$	**Thermal Conductivity** $(\frac{W}{m} \cdot k)$	**Thermal diffusivity** $\alpha = \frac{k}{\rho c} \cdot 10^6(\frac{m^2}{s})$
Aluminiumaluminum	2707	896	2.4255	204 at 20C	84.100
Brick	1698	840	1.4263	0.69 at 29C	0.484
Brick Magnesia	3000	1130	2.5310	5.07	1.496
Concrete	2240	1130	2.5310	0.9 - 1.3	0.356 – 0.514
Cast iron	7900	837	6.6123	29.3	4.431
Copper	8954	383	3.4294	385 at 20C	112.300
Earth (wet)	1700	2093	3.5581	2.51	0.705
Earth (dry)	1260	795	1.0017	0.25	0.250
Stone, granite	2640	820	2.1648	1.73 to 3.98	0.799 - 1.840
Stone, limestone	2500	900	2.2500	1.26 to 1.33	0.560 – 0. 591
Stone, marble	2600	800	2.0800	2.07 to 2.94	0.995 – 1.413
Soapstone	2956	840	0.785	12.5	1.172 – 1.579

Source: Adeyanju (2015).

The cast iron is the material with higher heat capacity, as presented in the Table 7, but it is heavy, and low thermal conductivity. The Copper has also ideal properties, but it is relative expensive. The stones and earth are more abundant available around the world, but the storage technology is not known at all.

The authors are hopeful that more initiatives of this kind can appear so that there is more related research of review can be developed to influence policies to embrace this purpose of sustainable energy use and diversification of the Mozambican energy matrix. Such policies can influence the massive use of solar collectors with clear measures of electricity use limits for water heating, as well as capacity building with similar methodologies mentioned by the team of Chichango, et al.., (2023a) that are inclusive and comprehensive.

4. Conclusion

The conclusion of this review paper on potential materials for the construction of an alternative flat-plate solar collector, highlights the importance of selecting appropriate materials to maximize the efficiency and durability of solar collectors. Materials should be chosen based on their thermal compatibility, corrosion resistance, heat transfer efficiency, joining methods, cost and availability, operating temperature range, and longevity. The study suggests that for conditions such as those in Mozambique, alternative materials such as non-tempered glass and UV-resistant polymers may be viable options to reduce costs. In addition, thermal energy storage (TES) is crucial for balancing the energy supply and allowing the use of surplus heat collected during the day in periods of lower sunshine or at night. The research underscores the need for further studies to explore alternative materials and thermal energy storage technologies that are cost-effective and effective for residential use in areas with limited energy infrastructure, and availability of soapstone in the country, and the knowledge of its heat storage properties, may be an opportunity to evaluate the integration of these stones into alternative flat plate solar collectors, for performance improvement. In addition, the author also suggests to investigate the use of polymers from recycled process to replace metal parts in the solar collector.

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References

Adeyanju, A. A. (2015). Thermal Energy Storage Techniques; *Sci-Afric Journal of Scientific Issues, Research and Essays* 3(5), 26-736http://www.sci-africpublishers.org.

Akbar, M. A.; Manzoor, T.; Danaish et al. (2022) - thermal analysis of flat plate solar collector for different temperature variations. *International Journal Energy Water Res* 6, 315–321 (2022). https://doi.org/10.1007/s42108-021-00177-7.

Alghoul, M. A.; Sulaiman, M.Y.; Azmi, B.Z.; Wahab, M. (2005). Review of materials for solar thermal collectors. *Anti-Corrosion Methods and Materials*. 52 (4); 199–206. 10.1108/00035590510603210.

Amrizal, A., Ahmad Yonanda, Z.. (2017). Comparison Study of Solar Flat Plate Collector with Two Different Absorber Materials. Proceedings of the 1st Faculty of Industrial Technology International Congress. Bandung, Indonesia: Universitas Lampung1Bandung, Indonesia: Universitas Lampung.

Arthur, F., Nhumaio, G., Saide, A. and Cumbe, F. (2015) Solar Thermal Technology Roadmap for Mozambique. *Scientific research an academic publisher*; 1-27.

Bittar, A. (2013). Solar Selective Coatings: Current Status and Future Trends. Source: International Workshop on Design of Sub-Systems for CSP Technologies, IIT Jodhpur, 19-21. iitj.ac.in/CSP/material/19dec/selective.pdf.

Chichango, F., & Cristóvão, L. (2021). Mozambique Solar Thermal Energy Technologies: Current Status and Future Trends. *Journal of Energy Technologies and Policy*, 11(5);13-17. 10.7176/JETP/11-5-02.

Chichango, F., & Cristóvão, L. (2024). Review of literature on methods and processes to produce bioethanol from banana peels for disinfection and sanitation of the environment in communities, central region of Mozambique. *Research, Society and Development*, 13(3), e12713344921-e12713344921.

Chichango, F., Cristóvão, L., & Mahanuque, O. (2023a). Empowering women through vocational training: Evidence from rural areas affected by armed conflict in Mozambique. *Research, Society and Development*, 12(14), e108121441196-e108121441196.

Chichango, F., Cristóvão, L., Muguirima, P. & Grande, S. (2023). Solar Dryer Technologies for Agricultural Products in Mozambique: An Overview. *Research, Society and Development* 12(4): e6812439850.

Chichango, F.; Meque, P.; Cristóvão, L. (2021) Reabilitação das Centrais de Chicamba e Mavuzi. *Scientific Journal of Mathematics, Natural and Applied Science- Munyo*, 4(2); 53 – 63.

Cristóvão, L., Chichango, F., Massinga, P.H., & Macanguisse, J. (2021). The Potential of Renewable Energy in Mozambique: An Overview. *Journal of Energy Technologies and Policy*. 11(5) 13-17. 10.7176/JETP/11-5-02.

Douvi, E., Pagkalos, C., Dogkas, G., Koukou, M. K., Stathopoulos, V. N., Caouris, Y., & Vrachopoulos, M. G. (2021). Phase change materials in solar domestic hot water systems: A review. *International Journal of Thermofluids,* 10, 100075.

Duffie J. A. and Beckman W. A. (2013). *Solar Engineering of Thermal Processes*. 4ed, pp928. John Wiley & Sons, Inc., Hoboken, New Jersey.

Evangelisti, L., Vollaro, R. D. L., & Asdrubali, FLatest advances on solar thermal collectors: A comprehensive review. *Renewable and Sustainable Energy Reviews,* 114, 109318.

Farulla, G.A.; Cellura, M.; Guarino, F.; Ferraro, M. (2020). A Review of Thermochemical Energy Storage Systems for Power Grid Support*; Appl. Sci.* 10, 3142. 10.3390/app10093142,

Fedkin, M. (2024). EME 811: Solar Thermal Energy for Utilities and Industry. Pennsylvania State University. Retrieved from e-education.psu.edu/eme811.

Galvão, M. C. B., & Ricarte, I. L. M. (2019). Revisão sistemática da literatura: Conceituação, produção e publicação1. *Logeion: Filosofia da Informação*, 6(1), 57-73. https://doi.org/10.21728/logeion.2019v6n1.p57-73.

Ganjoo, A., McCamy, J., Polcyn, A., Ma, Z., Medwick, P.A. (2019). Glass and Coatings on Glass for Solar Applications. In: Musgraves, J.D., Hu, J., Calvez, L. (eds) Springer Handbook of Glass. Springer Handbooks. Springer, Cham. https://doi.org/10.1007/978-3-319-93728-1_48.

Garg, H. P. (1986). Absorber Plate Configuration and Optimization. In: Garg, H.P. (eds) Solar Water Heating Systems. Springer, Dordrecht. https://doi.org/10.1007/978-94-009-5480-9_7.

Gary. (2008). The Renewable Energy site for Do-It-yourselves Available in line in Build It Solar: Solar energy projects for Do It Yourselves to save money and reduce pollution (accessed Mach 2nd,2024).

Gorgolis, G., & Karamanis, D. (2016). Solar energy materials for glazing technologies. *Solar Energy Materials and Solar Cells*, 144, 559-578.

Gunreddy, N.; Mulamalla, A.R.; Duraisamy, S.; Sivan, S.; Poongavanam, G. K., & Kumar, B. (2022). Conductive and convective heat transfer augmentation in flat plate solar collector from energy, economic and environmental perspectives — a comprehensive review. *Environmental Science and Pollution Research,* 29(87019-87067) .

Laskar, S. (eds) Emerging Technologies for Smart Cities. Lecture Notes in Electrical Engineering, vol 765. Springer, Singapore. https://doi.org/10.1007/978-981-16-1550-4_21.

MacDonald, T. H (1951). Some Characteristics of the Eppley Pyrheliometer, Monthly Weather Rev., 79(8), 153.

Medyk, A. B.; Mendes, A. S.; Libório, L. G. & Martimbianco, A. L. C. (2022). Systematic reviews. Students for Better Evidence. Cochrane. Available at: [Systematic reviews - Students for Better Evidence (cochrane.org)].

Meque, R., Cristóvão, L. & Chichango, F. (2023). Socio-Environmental Impacts Caused by Tropical Cyclones Idai and Eloise in Sussundenga District, Mozambique. *Research, Society and Development* 12(14): e 72121440818. 10.33448/rsd-v12i14.40818.

Modernize (February 12th , 2024) Available [online] https://modernize.com/homeowner-resources/solar/passive-versus-active-solar-hot-water-heaters.

Ogueke, V.N.; Anyanwu, E.E.; Ekechukwu, V. (2009). A review of solar water heating systems. *Journal of Renewable and Sustainable Energy* 1, 043106 (2009). 1704310617. 10.1063/1.3167285
.

Rojas, P. R. (2021). Home Solar Water Heater, https://www.misolarcasero.com/en/

Sadhishkumar S. & Balusamy. T. (2014). Performance improvement in solar water heating systems—A review. *Renewable and Sustainable Energy Reviews,* 37; P191-198. https://doi.org/10.1016/j.rser.2014.04.072.

Sakhaei, S. A., & Valipour, M. S. (2019). Performance enhancement analysis of the flat plate collectors: a comprehensive review. Renewable and Sustainable Energy Reviews, 102, 186-204.

Sarma, D., Barua, P. B., Rabha, D.K., Verma, N., Purkayastha, S., Das, S. (2021). Flat Plate Solar Thermal Collectors—A Review. In: Bora, P.K., Nandi, S.

Sharma, P., Torralba, A., & Andreas, J. (2022). Skill Induction and Planning with Latent Language*Proceedings*Language Proceedings of the 60th Annual Meeting of the Association for Computational Linguistics (Volume 1: Long Papers), 1713–1726.

Thakur, A., Kumar, S., Kumar, P., Kumar, S., & Bhardwaj, A. KA review on the simulation/CFD based studies on the thermal augmentation of flat plate solar collectors. Materials Today: Proceedings, 46, 8578-8585.

Tian, Y. (Yuan) and Zhao, Changying (2013). A review of solar collectors and thermal energy storage in solar thermal applications. *Applied Energy*, 104, 538-553. 10.1016/j.apenergy.2012.11.051.

Tripathi, M., Chauhan, P. S., Amar, A. K., & Tiwari, S. K. (2018). Solar Thermal Collector Materials–A Review. *International Journal of Thermal Energy and Applications*, 4(1).

Universe today (2013). Space and astronomy news available online: Seasons1.svg_.png (800×469) (d1jqu7g1y74ds1.cloudfront.net). University of California Natural Reserve System, UCSB (2024). Indirect solar hot water system.

Variava J. & Bhavsar A. (2017). Review of renewable energy the solar water heater system. International Journal of Advance Research Andand Innovative Ideas In Education. 3(1 2017):7.

VQuaschning (2004). Solar thermal water heating Technology Fundamentals published in Renewable Energy World February 2th, pp. 95-99 https://www.volker-quaschning.de/articles/fundamentals4/index.php.

Wang, K., Qin, Z., Tong, W., & Ji, C. (2020). Thermal Energy Storage for Solar Energy Utilization: Fundamentals and Applications. In M. Al Qubeissi, A. El-Kharouf, & H. S. Soyhan (Eds.), Renewable Energy - Resources, Challenges and Applications (pp. 1-22). IntechOpenIntech Open. 10.5772/intechopen.91804.

Weiss, W. & Dur, M. S. (2019). Solar heat wouldwide. Global Market Development and Trends in 2018, Detailed Market Figures 2017, p. 83.

Wojcicki, D. J. (2015). The application of the Typical Day Concept in flat plate solar collector models. *Renewable and Sustainable Energy Reviews*, 49, 968-974.

Zaboli, M.; Saedodin, S.; Ajarostaghi, S.S.M. et al. (2023). Recent progress on flat plate solar collectors equipped with nanofluid and turbulator: state of the art. *Environ Sci Pollut Res* 30, 109921–109954. https://doi.org/10.1007/s11356-023-29815-9.

Zheng, J.; Febrer, R.; Castro, J.; Kizildag, D.; Rigola, J. (2024). A new high-performance flat plate solar collector. Numerical modelling and experimental validation. *Applied Energy*: 35, 1-14: www.elsevier.com/locate/apenergy.