INTRODUCTION OF PHOTOVOLTAIC THERMAL COLLECTOR HYBRID SYSTEM FOR IMPROVEMENT OF PERFORMANCE OF PV MODULE A SUSTAINABLE DEVELOPMENT

Abstract

Based on the most advanced system components for photovoltaic-thermal (PVT) technologies, this study investigates the convincible contribution of PVT solar collectors to sustainable progress. PVT technologies are a capable way to reduce the excess heat generated by PV panels while also significantly lowering the cost of production and improving energy output. Therefore, the PVT industry's and researchers' ability to reduce the complexity and cost of their present systems in a way that can close the productiveness and price gap with both PV and (ST) Solar Thermal systems is crucial to the technology's development. The information presented in this book chapter was learned after extensive research on PV technology, working, classification, literature review, performance calculation, application and market status, and project growth, which various PVT experts with extensive experience in developing PVT technologies. This knowledge lays the groundwork for PVT solar collectors that are more effective and affordable.

Keywords: Solar energy, PVT collector, Performance calculation, PV application, market analysis

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I. INTRODUCTION

Energy is becoming more and more in demand as a result of society's advancement. Additionally, power contributes to bettering welfare and health. All nations require energy for basic human requirements like cooking, lighting, movement, communication, and comfort. Because of this, the use of fossil fuels has increased fossil fuel generates carbon emissions and greenhouse gases. And affect the environment. Using green technology like solar, wind, geothermal, etc., reduces the effect of greenhouse gases and saves the environment. Solar energy originates from the Sun. and is converted to heat and electricity. Without generating any emissions for the environment, most energy that hits the earth's surface is absorbed, with very little energy reflecting off it. The 30% of incoming radiation does not heat the earth deflected into space. In contrast, the environment and the planet's surface absorb around 70%.[1-2].

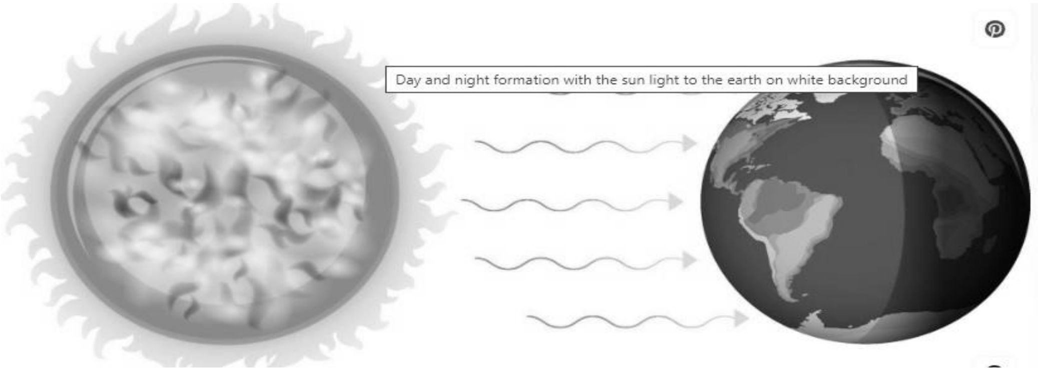

Figure 1: Radiation emitted by the sun on the earth.

Solar energy is a most effective source of green energy, and it can be used in two methods direct and indirect Solar Techniques. Examples of direct solar capture techniques are concentrated solar power and water heating with sunlight. Indirect solar systems convert sunlight into usable heat and offer air movement for ventilation to heat and cool spaces without requiring active mechanical or electrical equipment. [3]

1. **PV Technology:** The photovoltaic effect is used by solar cells to convert sunlight directly into electricity. Sunlight photons that strike the solar cell and are absorbed by the semiconductor material produce energy. The semiconductor electrons are excited by this, which causes the electrons to flow and produce a proper electric current. Direct current (DC) is the name given to the electricity produced since the current only flows in one direction. Solar cell arrays in parallel and series are integrated into a panel known as a photovoltaic (PV) module. Both grid-connected and off-grid uses, such as those in homes, businesses, industrial facilities, isolated locations, and power plants (utility PV systems), utilize the generated electricity. [4], the primary element of a PV system is display in Figure 2.

- PV Module, which is the power source.
- Charge Controller to avoid overcharging of the battery.
- Battery to save power and use when there is no sunlight.
- DC distributor panel for fuses, switches, or circuit breakers for any protection.

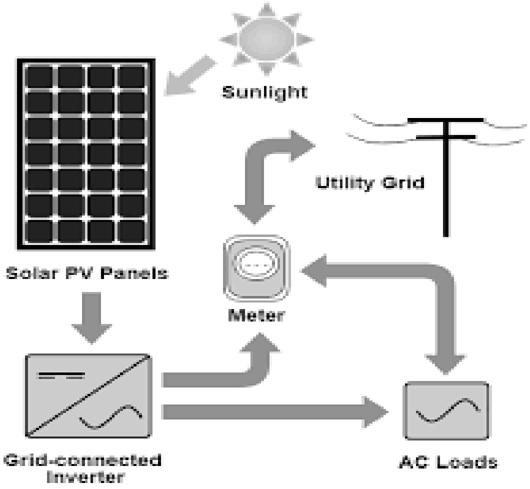

Figure 2: primary element of a PV structure

2. **Operation of solar (PV) cell :** Conversion of solar radiation to electric current PV cells involves two essential steps.

- The solar cell absorbs solar radiation and produces an electron-hole pair of positive and negative charges.

- Positive and negative charges are divided by a potential gap inside the cell. The substance used to create the cell must absorb the energy present in each photon of sunlight. The equation connects a photon's energy, E, to its wavelength, λ

$$E = \frac{hc}{\lambda}$$

Where h *is* the Planck constant = 6.626×10^{-34} Js, c is the velocity of light in a vacuum = 3×10^{8} m/s, E is in electron volt (eV) and λ is the wavelength of light in μm.

The two energy bands in which the electrons in a semiconductor can be found are the balancing band and the conduction band. The electrons in the valence band are entirely covered, whereas the electrons in the conduction band are at a greater energy level and are not. The energy Eg difference can distinguish the electrons' energy levels of the two bands. Some of these excited electrons cross the frequency gap from the valence band to the conduction band when sunlight releases photons with energy E more significantly than the band gap energy E_g, leaving holes in the former. They generate these electron-hole pairs. Both the holes and the electrons in the valence layer are mobile. If there is a potential difference within the cell, they can be split apart and produced through an external circuit (photovoltaic effect). [5, 6]

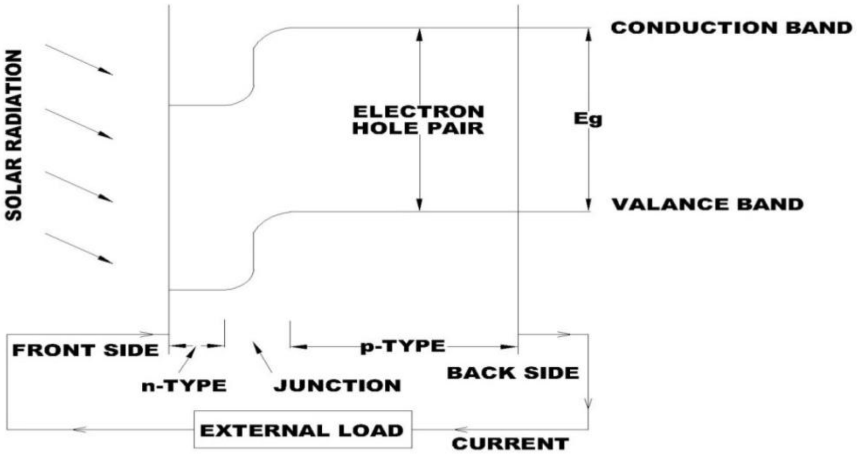

Figure 3: Principal of working of solar cell

3. **Types of PV (module) technology:** The development PV cell technologies are classified in there major groups, First generation (mono crystalline silicon, polycrystalline silicon), Second generation (thin film silicon cell) and Third generation PV technology

   - First generation: Based on silicon. Dominated the global solar cell market because to their maturity, longevity, and relatively high efficiency.
   - Second generation: Solar cells with a thin layer. Only a few micrometers thick of semiconductor materials make up their construction. Although they are produced more quickly and are offered at lower rates, their lifespan and efficiency are typically shorter.
   - Third generation: Innovative solar gathering technique in its entirety. Advanced thin-film, concentrated PV, concentrated solar thermal, and perovskite solar cells are just a few. Some still require more research and development to be mass-produced and cost-effective.[7]

     - **Mono crystalline silicon:** The earliest kind of solar cells is manufactured of mono-crystalline silicon. They have a continuous lattice and nearly no flaws because they are formed of pure silicon crystals. High light conversion efficiency (often 15%; newer advances by Sun Power claim enhanced efficiencies up to 22–24%) is made possible by its features. The problematic manufacturing process for Si crystals drives up the price in this solar manner. Current innovations have reduced the thickness of Si material utilized in mono-crystalline cells to reduce costs. The standard color of the mono-crystalline silicon cells is either black or blue. The operating modules may need to be replaced more frequently due to mono-crystalline silicon cells' high durability and length. The main disadvantages of silicon panels are high initial cost and mechanical vulnerability. [7, 8]

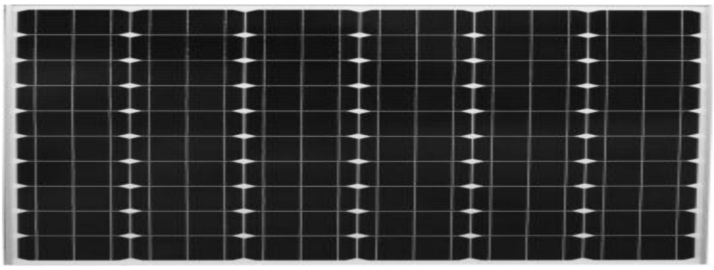

Figure 4: Mono crystalline silicon cell and module. [7]

- **Polycrystalline (multi crystalline) silicon:** Thin wafers of silicon crystals are assembled into multi-grain and multi-plate polycrystalline cells. Because it is simpler and less expensive to make smaller silicon bits, this PV has minimum production costs than mono-crystalline silicon cells. The performance of the polycrystalline cells is around 12% minimum. The mosaic-like display of these cells makes them easy to identify. Polycrystalline cells are also powerful and may have more than 25 years of service life. Low conversion efficiency and mechanical brittleness are drawbacks of this PV technology. [7]

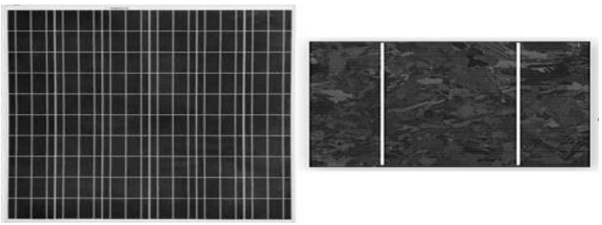

Figure 5: Poly crystalline silicon cell and module.[8]

- **Amorphous silicon (Thin-film):** Silicium films are saved over substrate glass to make thin film photovoltaic cells set against mono- or polycrystalline cells; this method requires minimum silicon for production; even so, the cost of this economy is reduced regeneration efficiency. The performance of thin-film PV is 6%, Set against 15% for single-crystal Si cells. Making a stratified structure out of numerous cells is one method to increase performance. The primary advantage of thin-film photovoltaic technology is that different substrates can save amorphous silicon. It can then be flexible and have diverse forms, making it suitable for various applications. The solar cell's performance is typically decreased by overheating, which is less likely to occur with amorphous silicon. The most advanced silicon for PV is amorphous silicon. [7, 9]

Figure 6: Amorphous silicon (Thin film) PV module [10]

II. PHOTOVOLTAIC MODULE

A packed, joined assembly of solar cells is fixed in series and parallel is called a photovoltaic panel. PV panels give the proper current and voltage levels for any application to offer full power. PV modules must also be safeguarded from environmental harm. Photovoltaic modules often make up this environmentally and electrically safe equipment. The module is then utilized alone or in conjunction with other modules from a solar array in an electrical circuit. [11]

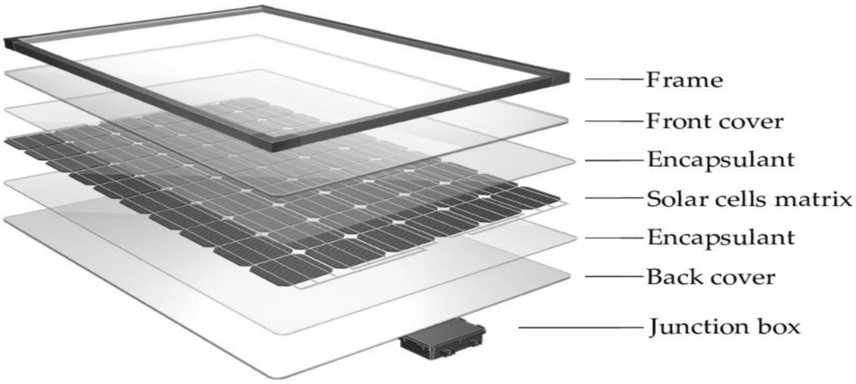

Figure 7: Scheme of the layers for a typical PV panel [11]

1. **Effect of temperature on solar cell:** The total irradiance, the spectral circulation of the irradiance, and the heat are the three most significant factors that explain the working conditions of a solar cell. The efficiency of solar cells is often assessed by the designers of the devices using the SRC (standard reporting conditions): illumination of 1000 W/m^2, operating temperature of 25°C, and AM1.5 reference spectrum. Since they don't take into account the actual geographic and meteorological factors at the accession location, these situation never arise during plan outdoor operations. Reverse saturation current increases quickly as temperature rises due to an increase in the photon production rate, which narrows the band gap. As a result, this causes little variations in current but significant changes in voltage. Each degree of temperature increase causes a 2.2 Mv reduction in cell voltage. The effectiveness of solar cells is negatively impacted by temperature. Therefore, solar cells function best on cold and sunny days rather than in hot and sunny weather. The open-circuit voltage in a solar cell is the element most impacted by a rise in temperature. Because I0 is temperature-dependent, the open-circuit voltage drops as the temperature rises. Given by is the equation for I_0 coming from a p-n junction's one side. [12-13]

$$I_o = qA\frac{Dn_i{}^2}{LN_D}$$

Where q is the electronic charge, D is the diffusivity of the solar cell, L is the diffusion length of the solar cell, N_D is the doping.

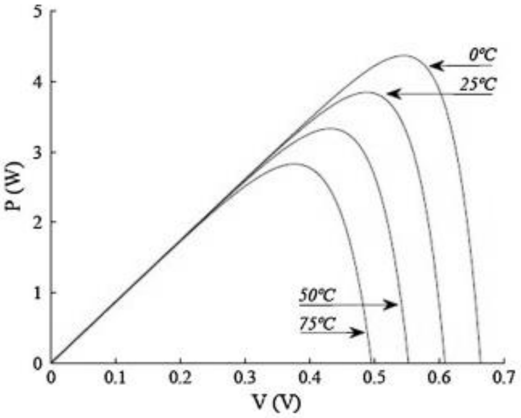

Figure 8: P-V characteristics with temperature variation [12]

2. **Spectrum distribution of Sun :** The solar spectrum (290–2500 nano meters, where 1 nano meter is 10^{-9} of a meter) is the range of wavelengths over which the sun radiates solar energy or sunshine. Applications of solar heat, the significance of wavelengths for solar heat applications are usually found in the solar spectrum's ultraviolet, visible, and infrared regions, ranging from roughly 0.3 to 2.4 m. The radiation outside this range heated the PV cells and may be applied as thermal heat, reducing the maximum electrical performance. PV cells perform optimally over a smaller range of the solar spectrum (i.e., between 0.3 to 1.1 m). Because heat and electricity are generated simultaneously, PVT collectors are more effective and utilize a broader range of solar irradiation. PVT collectors, which co-generate heat and electricity, a more comprehensive range of solar irradiation should be used, making them more desirable in terms of energy conversion performance, as shown in. [14]

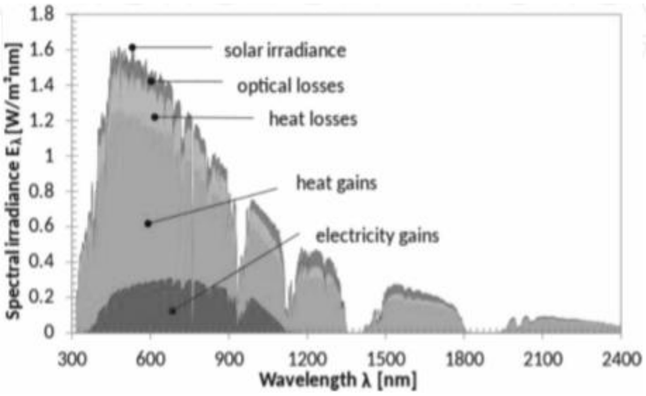

Figure 9: Spectral distribution of solar irradiance [14]

3. **Solar radiation:** The electromagnetic waves that the Sun emits are known as solar radiation. The solar rays that strike the Earth drive nearly all known physical and biological cycles in the Earth system. Three types of solar radiation were distinguished. Fig.10. showed the availability of solar radiation. [15]

- **Beam radiation**: Beam or direct radiation refers to solar energy that travels straight and is observed on the earth's surface without changing direction. For beam radiation calculation

$$I_b = I_N \cos\theta_z, \; I_d = \left(\frac{1}{3}\right)\left[I_{ext} - I_N\right]\cos\theta_z$$

- **Diffuse radiation**: The solar radiation received from the sun after the atmosphere has altered its direction. Anisotropic radiation makes up diffuse radiation.

  $I_T = I_b R_b + I_d R_d + \rho R_r \left(I_b + I_d\right)$
-
- **Global radiation**: The total solar radiation (Beam + Diffuse) that reaches a surface is called the global radiation.

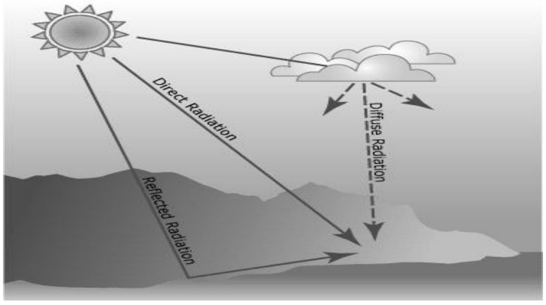

Figure 10: Solar radiation on the earth surface (beam, diffuse and direct radiation) [16]

III. PHOTOVOLTAIC THERMAL COLLECTOR

Solar collectors that concurrently transform solar radiation into thermal heat and electrical current are called photovoltaic thermal (PVT) systems. These devices combine a solar thermal and a photovoltaic cell. The collector stores the excess energy as heat while the photovoltaic cell turns electromagnetic radiation (photons) into electricity. The fluids typically utilized to extract heat from the collector include air, water, or occasionally a mixture of the two. The surface heat of a PV system significantly impacts its electrical performance; as surface heat decreases, electrical performance increases. These devices can produce more energy than solar photovoltaic's (PV) alone since they capture electricity and heat. The PVT system's appealing attributes include. [17-18]

- **Better efficiency:** The system has efficiency since it can produce both high-quality energy (electricity) and low-quality energy (thermal).
- **Rural areas:** In residential buildings, particularly remote locations, produced electrical energy must be used for lighting and thermal energy for space heating.

- **Cost-effectiveness:** A forced thermal heating system can be created to dry crops on-site, particularly medicinal plants. The farmers' living standards will improve as a result.

- The system can be mounted or integrated into the building structure without significant alteration. As a result, the lifetime cost will decrease.

- **Energy payback period:** Regardless of the type of PV module used, the system's energy payback period is shorter as it produces more energy than a PV system.

- **Carbon credit:** No pollution is produced because the system uses renewable energy sources. Utilizing such will assist in lowering greenhouse gas emissions in the environment.

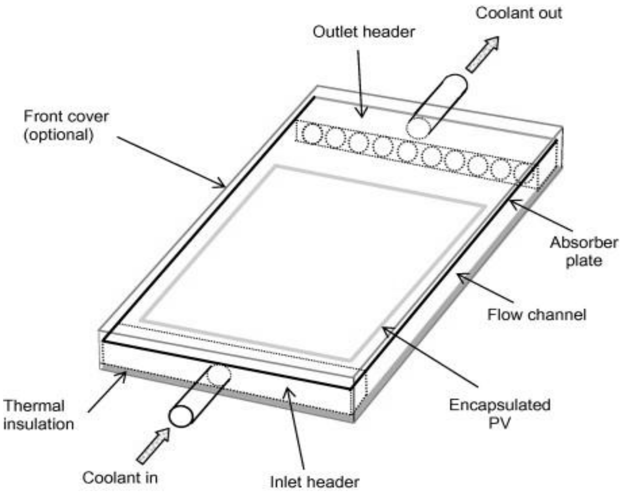

Figure 11: Photovoltaic thermal collector [17]

1. **Classification of PVT collector:** PVT collectors are divided into various groups based on the setup. We take into account three main categories. Design of the collector, working fluid kind, kind of covered panel. The comprehensive classification of the PV/T collector is display in Fig. 12. [19]

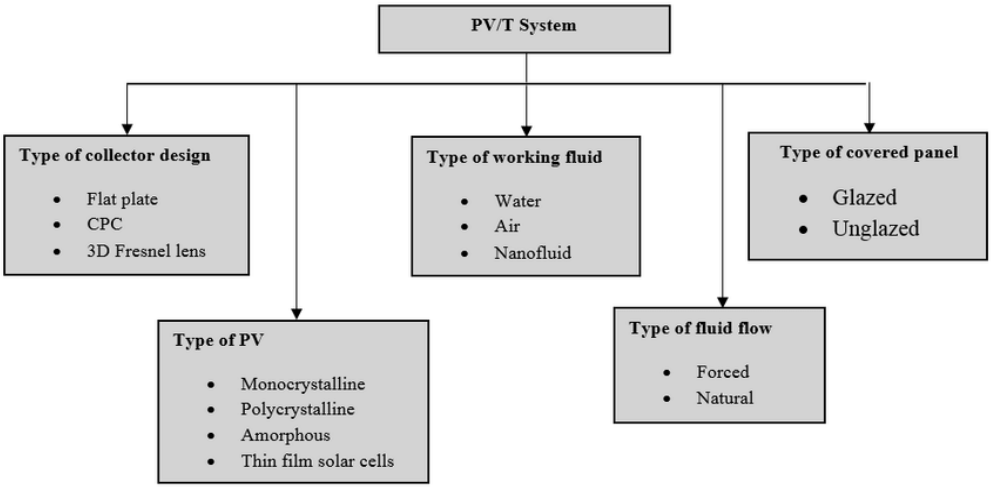

Figure 12: Comprehensive classification of PVT system [19]

- **Flat plate collector:** A flat plate collector, a solar panel apparatus, transformed solar radiation into heat energy. A more affordable heat that utilizes water as a working fluid. Heat is absorbed via a flat plate solar collector, transferring heat to the working fluid. It is appropriate for a variety of thermal applications. FPC typically works in a temperature range of 100° C. In addition, these gadgets have a low investment cost. The foundation of solar thermal devices is made up of FPC devices. They can be used in many contexts, from the domestic to the professional. Active room heating and water heating are the two primary uses for flat plate collector devices. [20]

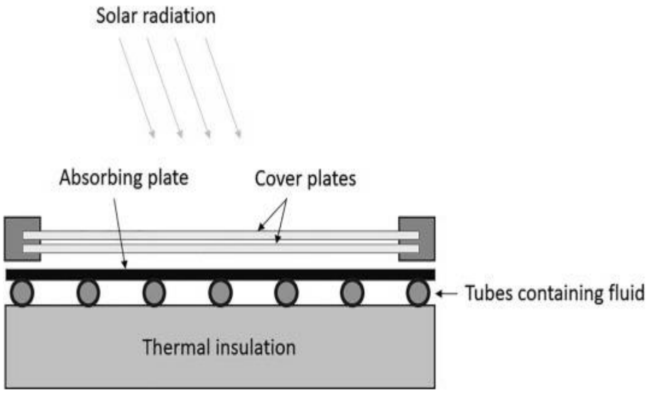

Figure 13: Schematic diagram of a flat plate collector showing its different components [21]

- **Compound parabolic concentrators:** Compound parabolic concentrators (CPC) are typical examples of non-imaging concentrators that can gather all available radiation, including diffuse and beam radiation, and guide it to the receiver. These concentrators appeal from the standpoint of system flexibility and simplicity because they do not have the same rigid constraints for the incidence angle as parabolic troughs. CPC concentrators can be used in linear (troughs) and three-dimensional (parabola cylinder) variants, like parabolic and other shapes. Troughs are the most popular and practical type of concentrator for this parabola, just like in "pure" parabola cases. [21]

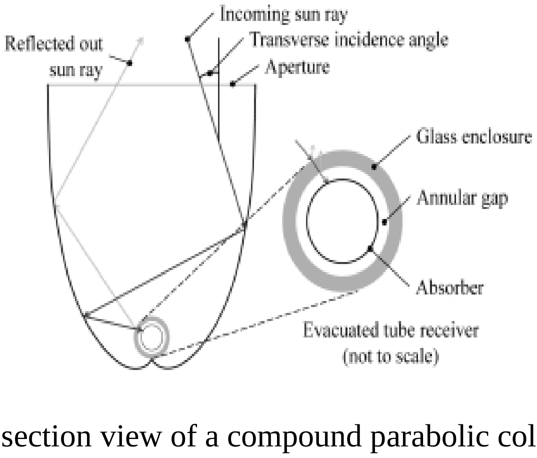

Figure 14: cross-section view of a compound parabolic collector (CPC) [21]

- **Glazed PVT collector:** Glazed systems minimize heat loss to the surrounding air by having an insulated side and back panel and a transparent top sheet. Modern panels' absorber plates can have an absorptive of above 93%. [15, 20]

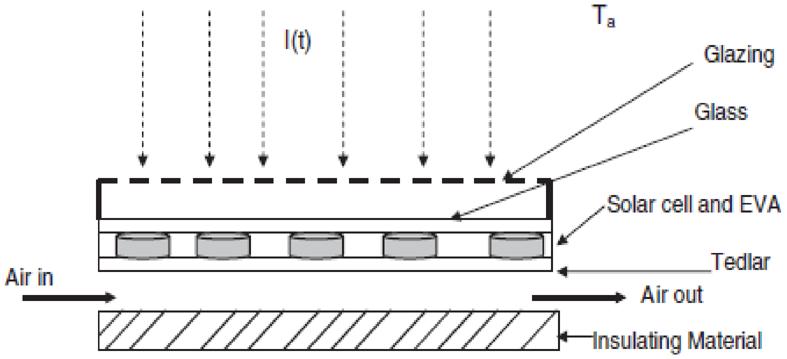

Figure 15: Cross-sectional view of Glazed PVT collector

- **Unglazed PVT collector:** Unglazed or transpired air systems consist of a heat-scrubbing absorber plate that air travels over or through. In commercial buildings, these systems are often utilized to pre-heat make-up air. These are some of the most effective technologies. [15, 20]

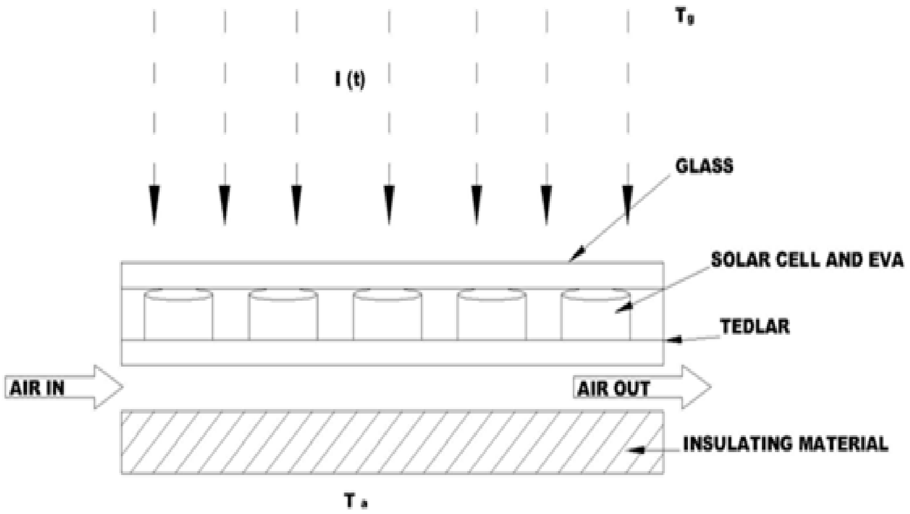

Figure 16: Cross-sectional view of unglazed PVT collector

2. **PVT air collector:** PVT collector is used as a heater for the air. Air is pumped in a space generated behind a PV panel (module) to heat and cool the air. Using air as a heat removal medium offers some benefits, including avoiding freezing and boiling of collecting liquid and harm in the event of a leak. This idea is depicted in Fig. 12. Low heat transfer from the system is produced by lower heat capacity and heat transfer rate, which is the main drawback. [15, 20]

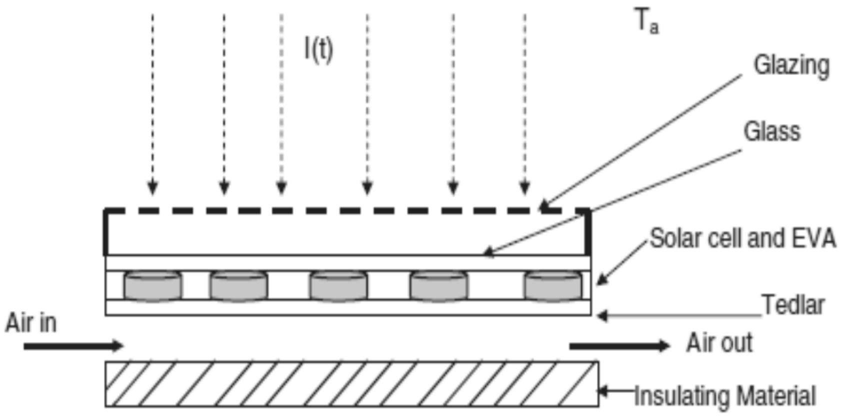

Figure17: Cross-sectional view PVT Air collector

- **PVT water collector:** Water PV/T collectors are alike to flat plate collectors. Water heating systems are made to heat the water while instantly generating energy. The PV cells of a PV/T collect a significant amount of solar energy, which helps to produce unwanted heat that can be recycled for pre-heating water and is mainly utilized for various home and industrial purposes. Water's sizeable specific heat capacity is a significant advantage over an air collector. To transfer heat. Another drawback is that water in PVT collectors freezes and boils. [21]

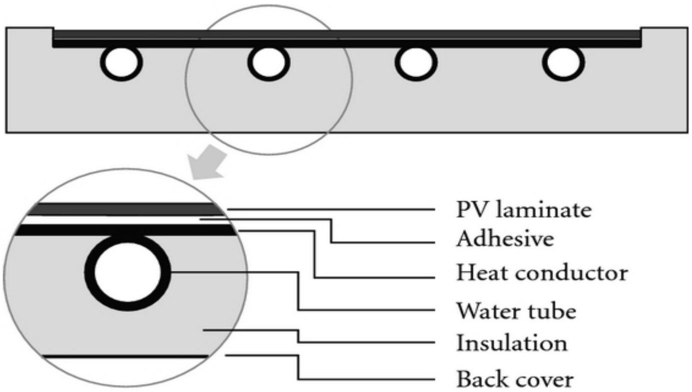

Figure 18: Cross-sectional view PVT Water collector [21]

- **PVT nano fluid collector:** Nano fluid is used in this collector to remove the extra heat from PV panels. A fluid that contains nano particles is referred to as a nano fluid. These liquids prepared interruption of nano particles in base liquids. The nano particles in nano fluids are typically created of metals, oxides, carbides, or carbon nano tubes. This fluid type has superior thermo physical characteristics than other liquid. Specifically, the rate of heat transfer of the liquid.[23]

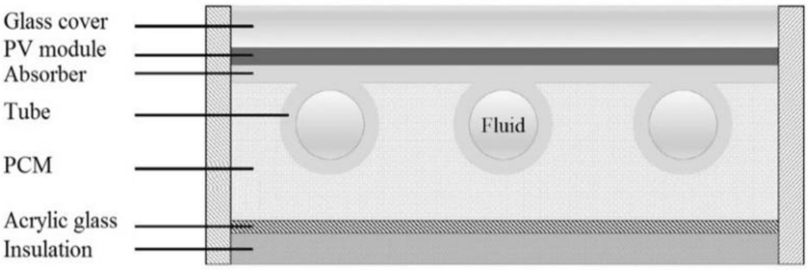

Figure 19: Cross-sectional view PVT nano fluid collector [24]

IV. HISTORICAL DEVELOPMENT OF FLATE PLATE PVT COLLECTOR

Lots of research is acted upon in design, performance affecting parameters and different cooling fluid use in flate plate PVT collector for optimizing the heat and electrical gain of the system.

Wolf (1976) A numerical investigation has been conducted for the effectiveness of a hybrid photovoltaic thermal collector connected to a heat storage tank. Using the weather in Boston, his assessment applies to a single residence. The outcomes demonstrated that combining a heat collector with a solar module is a workable strategy. After this examination, several studies examined a hybrid photovoltaic-thermal collector's heat and electrical gain. [25]

Bhargava et al.(1991) have examined the impact of a single-pass air heater's air mass transfer rate, air duct depth, length, and the percentage of the solar cells covering an absorber plate. They found that while the heat effectiveness of the solar cells was slightly enhanced, the average heat effectiveness for heating liquid and air was roughly 50–70% and 17–51%, respectively. [26]

Lalović et al. (1986) a flat-plate PVT collector was created and experimentally examined utilizing a new unblurred cell type. They demonstrated that the samples effectiveness as a less-cost, high-efficiency hybrid solar collector's design was both electrical and thermal effectiveness. [27]

Hegazzy (2000) Investigated different PVT air collector configurations, such as the airflow upper and lower PV modules, and mathematically assessed the electrical and thermal effectiveness of the airflow in both a single-pass and a dual pass configuration.[28]

Huang et al. (2001) Perform experimental investigation to compare the effectiveness of a photovoltaic-thermal collector to that of a standard solar collector. Their prototype was built using commercial polycrystalline cells. Their findings demonstrate that the hybrid solar collector analyzed saves more primary energy than the standard solar water heater and the PV module. [29]

Tripanagnostopoulos et al. (2002 Presented a study employing air and water heat exchange fluids to examine the capabilities of various hybrid PVT systems. They discovered that extraction with water heat is more effective compared to airflow. The findings also show that more glazing improves the hybrid solar collector's thermal efficiency. [30]. Othman et al. (2009) Studied the PVT air collector, the absorber plate has an additional del-grooved mounting. And compared to the alternative system's lack of del-grooved mounting, the finding has thermal performance. [31]. Sarhaddi et al. (2010) The effectiveness of PV/T air collectors was examined. As reported, the heat and electrical performance rose to 17.18% and 10.01%, respectively. [32]

Arslan et al.(2020). A PV/T collector employing air was evaluated numerically and experimentally at mass transfer rates of 0.045 kg/s and 0.031 kg/s. According to the findings, an average transfer rate of 0.045 kg/s had electrical and heat effectiveness of 13.98% and 49.5%, respectively. [33]

Many and varied studies in the literature have been carried out about PV modules cooling down through water and reducing their surface heat by applying different techniques, such as using a sprayer to spray water over the PV panel's front surface [34], spraying water [35,36] on PV surfaces, likewise immersing PV in water [35,36] since energy is so expensive. Since these early investigations, technology has undergone substantial progress. The articles mentioned above claim that cooling PV systems lower the cells' temperature, enhancing their effectiveness.

Bergene and Lovvik (1995) Examined a solar cell-incorporated flat plate collector on a theoretical level. They created several algorithms to determine a PVT system's heat and electrical effectiveness. They opined that such systems are as practical as home hot water service pre-heaters. [39]

Tripanagnostopoulos et. al. (2002) carried out research on composite PVT systems. employing PV cells made of both polycrystalline and amorphous silicon. They discovered that the thermal integration's cooling contributed to an improvement in PV cell efficiency of about 10%. They also discovered that liquid cooling offered superior cooling compared to airflow. Finally, they proposed that glazing or diffuse reflectors could further enhance the efficacy of these systems. However, they discovered that glazing the collectors would increase their heat performance at the expense of their electrical performance. [40]

He et. al. (2006) study a composit PVT system that circulates cooling water via natural convection was explored. They discovered they're system had a total efficiency of around 50%, with efficiency making up about 40% of that. They highlight that even though the heat efficiency was lower than a traditional thermo syphon solar water heater, the energy-saving performance was higher. [41]

Dubey and Tiwari (2008) performed a tested an outdoor PVT water collection for New Delhi's composit climate. According to their observations, PVT water collectors provide greater heat and average cell efficiency, which is consistent with the findings of other researchers. [42]

Tiwari et al. (2009) Examine a PVT water collector's energy and exergy performance and analysis. According to their findings, the PVT collector's total exergy and heat efficiency are highest at a warm water withdrawal transfer rate of 0.006 kg/s.[43]. Yazdanpanahi et al. (2015) Both experimental and numerical analyses were carried out on the PVT water collector. With a relative error of 3.96%, it has been demonstrated that the numerical results accurately match the experiment's measurement. The PVT water collector has a fantastic energy efficiency of 13.95%. [44]

In recent years, more research and development of nanofluid-based PV/T collectors have been done. The term "nanofluid" refers to a fluid comprised of nanoparticles combined with a base fluid with better thermo physical qualities overall and better thermal conductivity than water. The cooling of nanofluids in PVT systems is influenced by the fluid's viscosity, density, and thermal conductivity, referred to as the fluid's thermo-physical characteristics, and are higher in nanofluids than in the base fluid. [45-46] Sardarabadi et al (2016). The electrical, thermal, and energy efficiency of the Ag/water nanofluid-based photovoltaic/thermal (PV/T) system was investigated. The results showed that utilizing a four-weight percent nanofluid as a coolant could increase a PV panel's power output by 10% compared to using it. It also had 30% higher energy efficiency. [32]

Ali Najah et al (2016) Perform experimental study on the SiO2, TiO2, and SiC nanofluid-filled rectangular tube absorbers utilized in solar thermal collectors. According to the research, the SiC nanofluid PVT collector has a higher PVT electrical efficiency of 13.25% and a higher combined photovoltaic thermal efficiency of 81.73%. [46].
Jin et al.(2017) Fe_3O_4 nanoparticles were combined with an ethylene glycol/water (1:1, v/v) solution including various quantities of methylene blue or copper sulfate. They discovered that the direct splitters' spectrum absorptivity was on par with ideal filters for Si and InGaP PV cells. [48]

Zhou et al.(2018) Zhou et al. (2018) Investigated the heat distribution in a PV/T collector using a coiled tube. The study focuses on the influence of distribution on the winding cooling tube design. To optimize the design of the cooling tube, both the pressure drop and the thermal impact must be carefully considered. [49]

S. Mishaa et al. (2019). Calculate the surface and exit water temperatures using numerical simulations based on the PVT model, with radiation exposure of 600, 800, and 1000 W/m^2 and mass transfer rates of 2, 4, and 5 LPM, respectively, and an inlet liquid temperature of 26 ^oC. Perform an experimental examination of the PVT water system and CFD simulations under real-world climate conditions in Malaysia. The experiment for this investigation was carried out outdoors in the Malaysian climate at various value mass transfer rates of 2–6 LPM. The CFD results were verified using the experimental results. [50]

Yuting et al. (2020) It looked at two distinct nanofluids as coolants while numerically evaluating a photovoltaic thermal collector. They found that Al_2O_3/water nanofluid PVT collectors outperform TiO2/water nanofluid PVT collectors in terms of performance. When the mass transfer rate of the nanofluid is 0.03 kg/s, the PVT collector's electrical output is noticeably more conspicuous. [51]

Jidesh et al. (2021) Experimental validation was done on a semitransparent photovoltaic-thermal composit collector using CuO nanofluid. The average decrease in SPV-THC PV module temperatures utilizing water and CuO nanofluid was 9 and 12 degrees Celsius, respectively. When compared to typical transparent solar panels, the electrical performance of SPV-THC rose by 11.2% and 5.9% when using CuO nanofluid and water, respectively. [52]. M. Khodadadi et al. (2022 Numerous studies demonstrate that adding nanofluids, nano-PCM, and other cooling techniques to PVT designs improves heat and electrical performance; one configuration achieved improvements in thermal performance of 72%, electrical performance of 13.7%, and total energy performance of 23% when compared to a standard PV setup. In comparison, another found a 6.9%–22% electrical performance boost with nano PCM/hybrid PVT. [53]

Heat storage systems use phase change materials (PCM) more frequently. Through phase transition, PCM can be employed whenever it is needed to store extra heat. The PV panel surface temperature can be reduced effectively with PCM. The choice of PCM depends on regional climate factors such as ambient temperature, where the PCM's melting point must be higher than the atmospheric temperature. [52]. in hot climates, PCM-based PV panels have demonstrated superior performance versus traditional PV panels. They can store a lot of energy, which explains this. However, the primary issue with PCM is their comparatively low heat transfer rate. [54]

Velmurugan et al., (2021) The PVT collector's PCM implementation increased the system's overall effectiveness. The PVT-PCM system had a payback period of four to fifteen years. [55]. Nizetic et al., (2021) Integrating PCM with solar PV systems enhanced the PVT system's thermal performance. Using latent heat storage PCM is the more effective way to store sun energy. The mass flow rate of the fluid affects how quickly the PCM charges. [56].

1. Effectiveness of the nanofluid-based PVT collector:

- **Thermal performance:** Thermal performance of PVT collector is the proportion between the collector's total solar energy received and the energy it produces as heat calculated by using equation no.1 [52]

$$\dot{\eta}_{th} = \frac{\dot{m}_n C_{pf}\,(T_{fo}-T_{fi})}{GA} \ldots\ldots (1)$$

Where m_f is the mass transfer rate of fluid, C_{pf} heat capacity of fluid, T_{fo} exit temperature of fluid, T_{fi} Initial temperature of fluid, G total solar radiation, A the collector's cross section

- **Thermal energy:** Useful heat gain is calculated by equation (2)

$$Q_{th} = \dot{m}_f C_{pf}\left(T_{fo} - T_{fi}\right) \ldots\ldots (2)$$

- **Electrical efficiency of PVT system:** The ratio of a PV module's actual electrical output to the rate of solar energy incidence on the module is known as the electrical efficiency of the module. Is calculated by the equation no. 3. [52, 45]

$$\eta_{el} = \frac{V_{max}\, I_{max}}{GA} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

  Where I_{max} maximum current, V_{max} maximum voltage and A for the collector area in m^2, and G solar radiation incident in PV panel, Eq. indicates how the performance of a PV module decreases as temperature rises. (3) Represents the conventional PV module's typical linear expression. Electrical performance.

$$\eta_{el} = \eta_{ref}\left[1 - \beta\left(T_{pv} - T_{ref}\right)\right] \ldots\ldots\ldots.\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

  Where T_{PV} is PV cell temperature, T_{ref} is reference temperature and β is temperature coefficient.

- **Total performance of PVT collector [43]**

- Total performance is a combination of (Thermal + Electrical) efficiency of the system

$$\eta_{ov} = \eta_{elc} + \eta_{th} \ldots\ldots\ldots\ldots.\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

2. **Pumping Power & Pressure Drop:** Pumping power of the PVT system is obtained by the equation no. (6) [52]

$$E_p = \frac{\dot{m_f}\Delta P}{\rho_f \eta_p} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (6)$$

Where ΔP a pressure is drop, and η_p is the standard pump efficiency and ΔP is a pressure drop on PVT system, ρ_f is the density of fluid.

$$\Delta P = {}^{4fl\rho V^2}/_{2d} + {}^{k\rho V^2}/_{2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

V is flow velocity of fluid is calculated by equation no. (8)

$$V = {}^{\dot{m}}/_{\rho_f A_t} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

Where k loss coefficient between entry and exit of pipe and f is the friction factor

3. **Energy of Photovoltaic thermal system:** The highest possible rate of work output from the PVT collector is called energy, which concerns the energy's quality. The energy notion for the solar module represents the most significant proportion of solar heat transferred to valuable work. The ratio of total output energy to total input energy determines a PV module's energy efficiency. Erhan Arslan, et al.'s model, is considered for energy efficiency computation [30].

$\eta_{exergy} = E_{xout}/E_{xin}$ ………………………………………………… (9)

The solar module's (PV) input exergy is dependent on solar radiation, the surrounding environment's temperature, and the sun's temperature.

$E_{xin} = A_c * G * [1 - 1.33\left(\frac{T_a}{T_s}\right) + 0.33\left(\frac{T_a}{T_s}\right)^4]$ ……………………………………… (10)

Where T_a and T_s is the atmospheric and sun temperature, respectively. The output exergy is the combination of the thermal and electrical exergy of the PV module.

$E_{xout} = E_{xthermal} + E_{xelectrical}$ ………………………………………………………… (11)

$E_{xthermal} = Q * (1 - \frac{T_a}{T_c})$ ………………………………………………………………… (12)

Q refers to heat loss, and T_c is the cell temperature and Q can be calculated by

$Q = U * A_c * (T_c - T_a)$ …………………………………………………………………… (13)

Where U is the overall heat transfer coefficient due to convection and radiation of the system the electrical energy is the output electric power ($V_{max}I_{max}$) of the photovoltaic module.

V. APPLICATION OF PV MODULES

Since they only need a modest quantity of power, photovoltaic systems are being employed more frequently to provide electricity for various uses. Building-integrated PV systems), transportation, agriculture, medical refrigeration, and streetlights all use solar energy.

1. PV Electrical application

- **PV in buildings (building Integrated PV systems):** The phrase "building integrated" describes PV systems that are mounted on a building's rooftop as well as systems that are incorporated into the building envelope. In light of this, the simplest way to define BIPV is as systems that can be easily combined with the actual building or the building's grid connection. When designing the system and the building, expert civil engineers, architects, and PV system designers are typically consulted to integrate such systems. A thorough examination Of the installation location is required to maximize electricity and solar radiation generation in this situation. Flexible rolls of BIPV are commonly mounted on building facades, window systems, and roofs. BIPV systems must therefore be oriented to fully use the unique conditions at the installation location because their views of the sun are frequently constrained. The temperature of the PV modules, shade, installation angle, and orientation are the only variables that must be considered for the BIPV systems to fulfil their multifunctional responsibilities. [57]

Figure 20: Building Integrated PV systems. [58]

- **PV in transport:** PV has historically been utilized in space as supplemental power. PV is increasingly employed to supply auxiliary power in boats and autos but is seldom used to produce motive power in transportation applications. However, recent developments in solar cell innovation demonstrated the cell's capacity to manage multiple hydrogen generations, creating one of the best candidates for alternative energy for cars. For many years, PV has been used to power calculators and novelty items. It is now possible to run a calculator for several years without changing the batteries because of advancements in combine circuits and low-power LCD screens, making solar calculators less popular. In contrast, solar-powered remote fixed devices have recently increased in popularity due to rising workforce costs for connecting to the mains electricity or scheduled maintenance. Parking meters, emergency phones, and temporary traffic signs are some applications. [58, 59]

Figure 21: PV in transport [59]

- **PV in agriculture:** Worldwide, PV units are successfully utilized for a water pump for people, animals, and plants. Water pumping is most suited for use with solar PV since water consumption rises on dry days with lots of sunshine. On a clear, sunny day, the SPV water pumping system should be able to produce at least 15,000 l per day for 200 Wp panels and 170,000 l per day for 2250 Wp panels. On farms, PV is often utilized to power distant electric fences. [58]

Figure 22: PV in agriculture

- **PV in street lights:** Solar photovoltaic Street lights can be utilized as perimeter illumination for industries, compound lights, street lights in layouts, etc. During the day, the photovoltaic panels recharge the batteries. An automotive sensor turns a powerful, high-efficiency light on at dusk, and the light is turned off automatically at daybreak. [60]

Figure 23: PV in street lights

2. Thermal application

Solar energy can be used thermally for a variety of purposes, including distillation, drying, cooking, space heating, space cooling, and water heating.

- **Water heating :** One of the most appealing technologies is solar water heating. solar thermal applications from an economic perspective. The liquid flat-plate collector and the storage tank, which should be situated above the level of the collector, are the two main parts of this simple, small-capacity natural circulation system suited for home use. Water heated by solar energy in the collector travels mechanically to the top of the water tank, which is replaced by cold water from its bottom. [15]

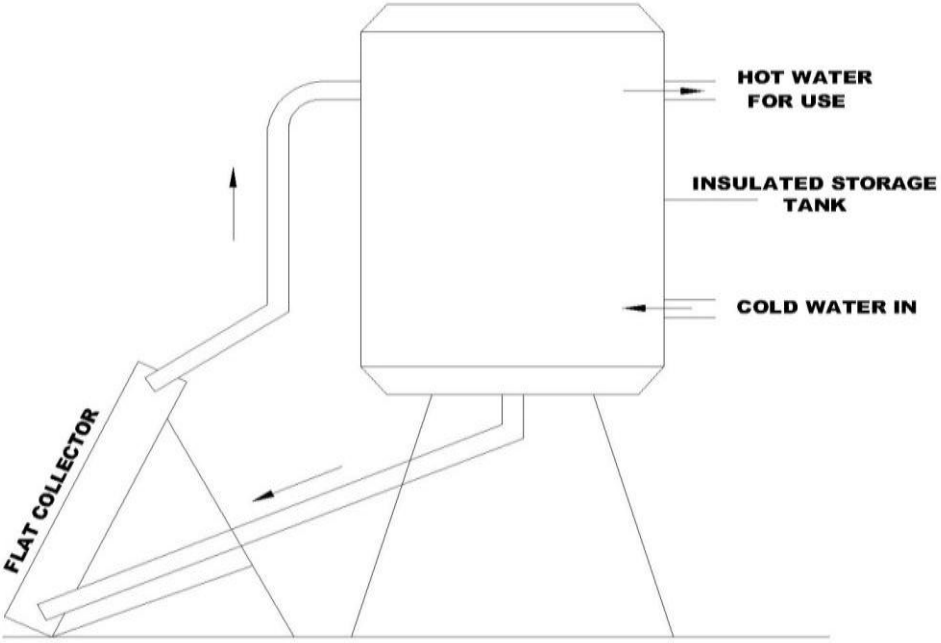

Figure 24: Natural circulation water heating system

- **Drying and Cooking :** Drying wood for construction and burning wood fuels like wood chips be done with the help of solar heat energy. Fruits, grains, and fish are among the food items that are produced using solar heat. Solar crop drying enhances quality while being cost-effective and eco-friendly. Ultralow cost pumped transpired plate air collectors based on black textiles are among the solar drying technologies. Solar heat energy helps to dry materials by raising the temperature while enabling air to pass through and remove the moisture like wood chips and other types of biomass. Sunlight is used for cooking food in solar cookers; reducing Solar cooking reduces fuel expenditures while removing a source of smoke, the demand for fuel or firewood, and air quality. The box cooker is the most basic sort of solar cooker. A transparent lid-covered, insulated container makes up a basic box cooker. These cookers usually attain temperatures of 50–100 °C and can be used well in partially cloudy conditions. [15]

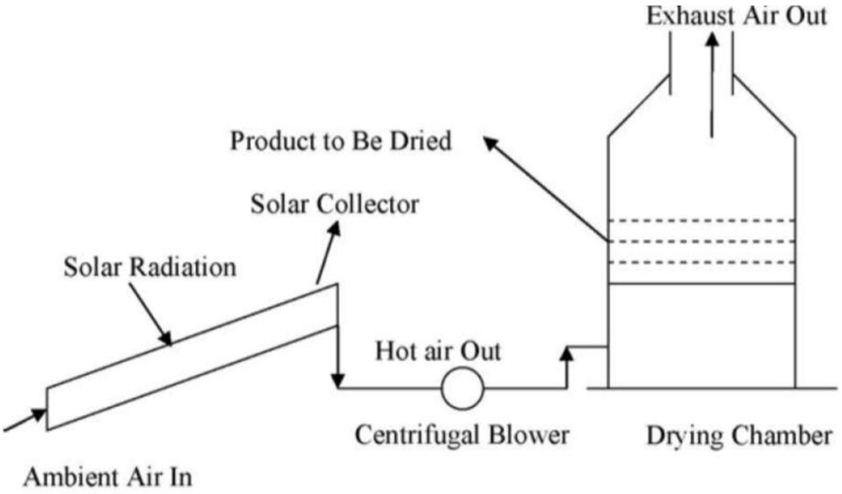

Figure 25: solar Drying system and components [60]

VI. PVT COLLECTOR MARKET STATUS

1. **Market over view:** The survey of 36 PVT collector manufacturers and PVT system vendors across 14 nations formed the basis for the PVT data. The total installed PVT collector area in 2020 was 1,275,431 m^2, with a capacity split between 232 MWpeak and 712 MWth (thermal). Europe (732,955 m^2) has the most PVT collector area installed, followed by Asia, with China excluded (306,098 m^2) and China (141,966 m^2), which combined makeup 659 MWth and 214 MWpeak of the installed capacity. Egypt and Israel account for 58,309 m^2 of the remaining installed collector area, while Ghana and South Africa account for 22,783 m^2, the USA for 7,248 m2, Australia for 1,639 m^2, and Latin America for 537 m^2. France leads the European market with an installed collector area of 500,992 m^2. Germany is second with 119,275 m^2, and the Netherlands is third with 57,420 m^2. Collector areas in Spain, Italy, and Swiss territory range from 12,600 m2 to 16,600 m^2. Additionally, collection areas in the remaining European nations are smaller than 11,000 m^2. [61]

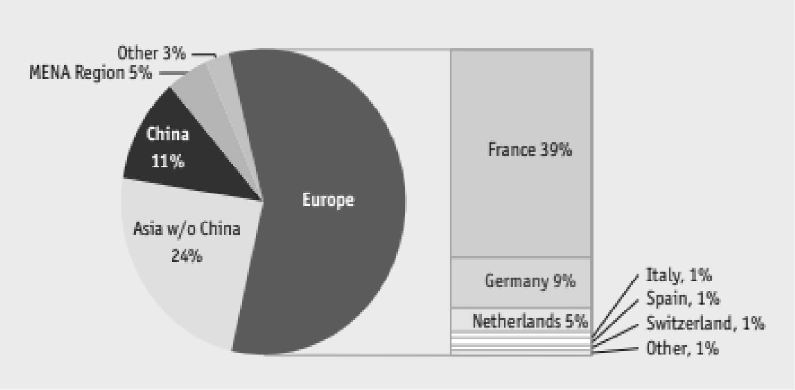

Figure 25: Distribution of the total installed collector area by economic region in 2020 (Source: AEE INTEC) [61]

2. **Market development of PVT collectors between 2017 and 2020:** According to the 36 PVT manufacturers' market data, the PVT market is expected to expand by an average of 9% between 2018 and 2020. With only a marginally slower growth rate of 8%, the European market similarly follows this pattern, increasing yearly new installed capacity by 31.7MWth and 10.5MWpeak.

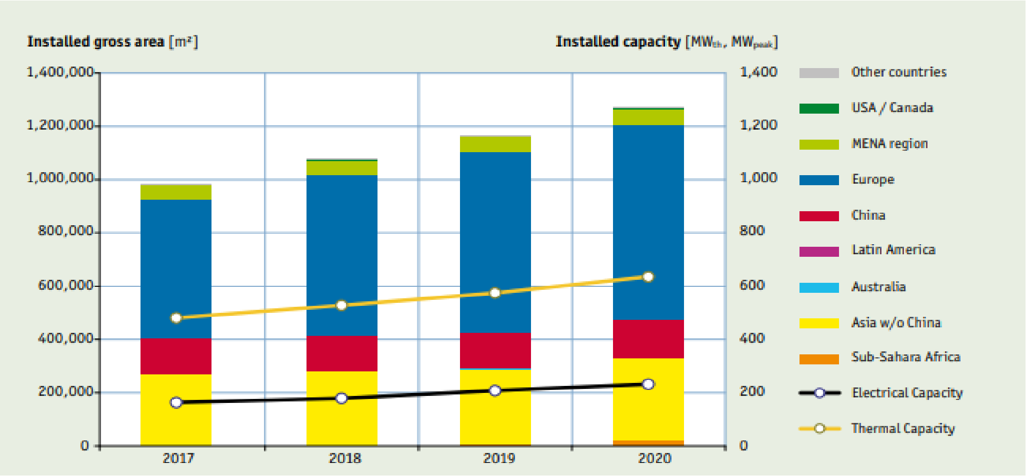

Figure 26: Global market development of PVT collectors from 2017 to 2020 (Source: IEA SHC Task 60 survey, AEE INTEC) [61]

VII. CONCLUSION

PVT technologies take advantage of remove excess of heat on the PV cells, increasing their overall performance, and utilizing this extra heat to raise the heat transfer fluid temperature of a solar heat system because PV and Solar heat technologies are combined in the same area. Suppose improved energy production performance achieves a sizable decrease in manufacturing costs. In that case, PVT technologies may be a competitive alternative to isolated systems like PV and ST solar collectors. Therefore, the ability of the PVT industry and researchers to reduce the complexity and cost of their present systems such that it can close the performance price comparison between The success of the technology depends on PV and ST technologies. As it is essential to achieving the objectives already stated in various environmental agreements, the significant proportion of emissions of greenhouse gases in the heat industry necessitates a severe and systematic decarburization through a appropriate technology mix, taking ST and PVT into consideration.

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VIII. NOMENCLATURES

A	Area (m^2)
w	Width (m)
c	Heat of material (J/Kg/K)
h	Heat transfer coefficient ($W/m^2/k$)
G,I	Solar radiation given by sun (W/m^2)
L	Different component thickness (m)
m	Mass (Kg)
$\dot{m}$	Mass transfer rate (Kg/sec)
Q	Use full heat gain
T	Temperature (^oC)
E	Exergy
PCM	Phase change material
BIPV	Building integrated Photovoltaic system
Si	Silicon
U	Total heat transfer coefficient from
Subscripts	
a	Atmosphere
PV	Photovoltaic
t_h	Thermal
el	Electrical
n_f	Nano Fluid
ref	Reference
S	Sun temperature
Greek letters	
η	Performance

k	Rate of heat transfer
µ	Dynamic viscosity (m^2/sec)
ρ	Density (Kg)
σ	Stefan Bolzman constant ($W/m^2/k^4$)

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