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Performance Review of Solar-Assisted Heat Pump Systems Using Solar Collectors, PV, and PVT Technologies

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ABSTRACT

Heat pumps (HP) can be used for a variety of residential, commercial, and industrial applications and offer a cost-effective replacement for conventional heat recovery systems. Hybrid systems that can be utilized for drying, heat storage, and water heating include solar-assisted heat pumps. Solar energy as a heat source for heat pump dryers improves performance and energy efficiency. This review aims to examine the concept of a solar collector, PV, and PVT technologies-assisted heat pump. The use of solar collectors to assist heat pump technology is a longstanding practice that remains in use today. Solar collectors that utilize direct solar heat sources and convert them into warm water or space heating are highly efficient. The concept of a PV and PVT-assisted heat pump is gaining popularity. The heat source utilized can be either single or multiple. Integrating a heat pump with a PVT as an evaporator result in higher heat performance. Using multiple heat sources is a more effective way to meet the cooling or heating requirements than relying on a single heat source. This review focuses on the mathematical modeling of a heat pump system integrated with PVT. Aspects of the mathematical model are critical for estimating the performance of heat pump systems in conjunction with solar collectors, PV, and PVT technologies. Readers who design and use heat pump technology must comprehend efficiency, COP, and configuration models.

1. INTRODUCTION

Indonesia possesses significant potential for solar energy owing to its equatorial location. Sunlight is widely accessible across various regions of the nation. Solar energy can be harnessed and transformed into either electrical or thermal energy. Photovoltaic or solar panels provide a convenient means of converting solar energy into electrical energy. According to the Ministry of Energy and Mineral Resources, the potential for electricity using solar panels in forest areas is around 3551 GWp, and the potential outside the forest areas is 1360 GWp. Furthermore, supposed the potential is multiplied by approximately 15% efficiency, the technical potential would be 533 GWp. The biggest potential for electrical energy from harvesting solar energy is in the Kalimantan Region, around 25%, followed by 32% in the Sumatra Region, and the rest are in other areas [1].

The potential of solar energy conversion into electrical energy through photovoltaic panels is highly promising in Indonesia. As per the Ministry of Energy and Mineral Resources, the government has set its sights on solar energy as the primary energy source, with a particular emphasis on converting electrical energy via solar panels. The yearly capacity of converting solar energy into electrical energy is estimated at approximately 1,377 kWh/kWp. If Indonesia were to achieve a solar panel electricity production capacity of 208 GWp, it would be sufficient to meet 111% of the country's electricity demand in 2018. The Institute for Essential Services Reform (IESR) estimates that the potential for solar energy to be converted into electricity is around 20 TWp, excluding agricultural and forest areas. By 2050, solar panels are predicted to become the dominant technology. In the coming 2050, the authority targets capacity to reach 45GWp. This estimate means 10.1% of the total renewable energy capacity will be fulfilled. Solar panels will be installed in up to 25% of residential, office, and government buildings. Likewise, manufacturing solar panels will be massively and vertically integrated [2].

In terms of cooling room temperature, people's demands continue to increase. Air conditioning is a common requirement for most residential and commercial buildings. The growing demand for air conditioning inevitably leads to increased energy consumption during its operation. In the upcoming years, there will be a persistent rise in the global energy demand for space cooling. The utilization of air conditioning systems is highly prevalent in office buildings, public residential areas, and healthcare facilities due to the high demand for such amenities. During the daytime, air conditioning units can effectively harness solar energy, particularly in regions with high and intense solar radiation

[3]. Using a heat energy source in Solar Thermal (ST) technology, an air source heat pump (ASHP) converts sunlight into heat energy through a collector. ASHP technology can produce heat or cool energy conforming to the user or consumer's settings. ST-ASHP technology applications can be applied to hot water, cooling, heating, and evaporation. Based on the power source, the ST-ASHP category is divided into two. First, it is powered by direct sun-assisted technology, and second, it is powered by indirect sun-assisted technology [4].

International energy agency reported that solar energy air heating and air conditioning systems are about 53 new generations. Currently, compressed air coolers using solar panels are very promising. Market demand for air conditioners powered by solar panels has a good opportunity [5]. Solar panels for room air conditioning are typically implemented in sizeable buildings that feature centralized air conditioning systems. The demand for air conditioning units in small residential and commercial settings has significantly increased due to the substantial drop in solar panel prices. Over the past decade, there has been a 70% decrease in the cost of solar panels [6].

In 1955, Sporn and Ambrose introduced the concept of a heat pump that utilized a solar collector, also known as the Solar Collector Assisted Heat Pump (SCA-HP) [7]. The SCA-HP technology continued to develop during the 1970s. Researchers have conducted studies on water heaters or warming water for home use. The promising opportunities in SCA-HP technology have motivated researchers to improve further their research in SCA-HP technology applications [8]. The idea of merging heat pump technology with solar collector technology to achieve lower warm water temperatures is viable [9, 10]. The performance of the SCA-HP technology is greatly influenced by various variables or factors that play a significant role in determining its effectiveness. Several variables or factors can have an impact, including component design, surface area of the solar collector, and storage capacity. Variations in these factors can impact technology performance optimization, as stated in SAC-HP [11].

The design configuration differences in SAC-HP technology significantly impacted the system performance. The commonly used configuration designs are the series model and the parallel model. The researchers are concerned about the reliability of the hydraulic design, as a good hydraulic design can optimize the system's performance [12]. The heat source plays a crucial role in optimizing SCA-HP technology's performance. Using technology with multiple heat sources is more optimal than relying on a single heat source. Combining solar or solar energy with other heat sources can significantly enhance the performance of SCA-HP technology, making it a more promising solution. Likewise, the impact of parallel or series system design models has been studied and developed to conserve energy in SCA-HP technology systems [13].

SCA-HP technology utilizes solar energy as a source of heat energy. In addition to other energy sources, solar energy is the primary source of SCA-HP. Solar thermal energy is a superior alternative to electrical energy for heating water, as it enhances system performance. Utilizing a solar collector facilitates the process of enhancing heat extraction [14, 15]. The integration of solar collector technology and a heat pump offers numerous benefits. One advantage is that it maximizes the absorption of solar energy during winter or when the intensity of the sun is low or little [16]. A decrease in sunlight intensity is common during cloudy weather or the rainy season. The limitations caused by low sun intensity, whether due to seasonal changes or weather fluctuations, can be overcome using SCA-HP technology. The SAC-HP technology can optimize the sun's low intensity by utilizing an effective collector design. Additionally, secondary heat sources can be combined when low or absent solar radiation [17].

The efficiency of a Heat Pump (HP) is significantly impacted by the variance in temperature between the condensation and evaporation stages. The performance of the HP system is impacted by temperature differences, which alters the energy sources. The performance of HP is subject to the influence of ambient air temperature, outdoor air temperature, and ground air temperature. These factors can impact the level of solar energy utilization. Numerous studies are being conducted on integrating HP technology and solar collectors to optimize solar energy utilization [18]. Solar power has the potential to be harnessed for both thermal and electrical energy conversion. The utilization of photovoltaic technology enables the conversion of solar energy into electrical energy in the form of DC/AC [19]. Heat pumps typically operate using alternating current (AC) to power their machinery. Direct current (DC) is utilized in various studies as a means to power high-performance machines [20]. The PV-HP system exhibits significant potential in its overall energy conversion efficiency [21].

Experts in this discipline have conducted numerous reviews or analyses. Recent energy analysis studies like Buker and Riffat's 2016 review have examined incorporating photovoltaic panels (PV) into building structures [22]. In 2017, Wang et al. reviewed the Solar Air Heat Pump system's potential for water heating, utilizing PVT and ground heat sources [12]. In 2018, Poppi et al. [23] reviewed the techno-economic analysis of solar air heat pumps for residential heating applications. In 2019, Nouri et al. [24] conducted a comprehensive review of the utilization of solar heat pumps, which utilize heat from the ground and employ PVT technology. In 2020, Wang et al. [25] reviewed heat pump technology incorporating solar collector, photovoltaic, and PVT technologies. In 2019, Shi et al. [26] reviewed the reliability and progress of heat pump technology that utilizes PVT technology to directly source heat. In 2020, Lazzarin et al. [27] reviewed and discussed the combination of heat pump technology with solar and PVT technology. Numerous authors have reviewed the design, configuration, and parameters of a heat pump integrated with solar collectors, photovoltaic technology, and thermal photovoltaic technology based on previous research reviews. In addition to its heating and cooling applications, such as warm or cold water and air, it can also be used for independent power generation.

Upon reviewing previous research and analyzing the results, it has become clear that there is a gap in the literature regarding the discussion of concept maps and mathematical models of solar collectors, PV, and PVT technologies-assisted heat pumps. The author has identified this gap based on their knowledge and research findings. This work novelty provides an overview of the concept map and the necessary parameters or variables to construct a mathematical model for PV-assisted heat pump technology, PVT, and solar collectors. In order to facilitate the development of mathematical models aimed at enhancing the COP and efficiency of heat pump technology, particularly those integrated with renewable energy, it is important to provide readers with relevant information.

2. CONCEPTUAL SCHEME OF SOLAR ENERGY-ASSISTED HEAT PUMP

Figure 1 shows the conceptual scheme of solar energy-assisted heat pumps. Solar energy is a source of heat energy in Solar Assisted-Heat Pump technology. Solar energy is the main source of Solar Assisted-Heat pumps, aside from other energy sources. A solar collector-assisted heat pump is a technology that directly harnesses solar energy and converts it into heat energy. Heat pump applications can be merged by either solar panel technology or photovoltaic, either directly or indirectly. Energy can be sourced from solar and air. PVT-assisted heat pumps are a technology that is currently in development. The PVT-assisted heat pump can be indirectly or directly assisted, utilizing energy sources such as air, diesel, and ground.

Utilizing solar thermal energy as a replacement for electrical energy in water heating enhances the system's performance. The augmentation of heat extraction is attributed to the solar collector that has been installed [14, 15]. The integration of solar collector technology and heat pump systems presents numerous benefits. One of the benefits is the optimization of solar energy absorption during periods of low sun intensity, such as winter or times of reduced sunlight [16]. A decrease in sunlight intensity is commonly observed during overcast weather or the rainy season. Solar Assisted-Heat Pump technology can mitigate the impact of weather fluctuations or seasonal changes on solar intensity. This technology can potentially optimize the utilization of low-intensity solar radiation through effective collector design. Furthermore, secondary heat sources can be used as a supplementary means of generating heat in situations where solar radiation is absent or insufficient [17].

The temperature differential between the condensation and evaporation stages significantly influences the efficiency of a heat pump (HP). The temperature variance impacts the HP system's performance as it alters the energy sources. The performance of HP is influenced by various factors such as ambient air temperature, outside air temperature, and ground air temperature, which can impact the degree of solar energy harvesting. Numerous researchers are currently investigating the integration of HP technology and solar collectors to optimize solar energy utilization [18]. Solar energy can be converted into heat energy and electrical energy. Photovoltaic technology can generate electrical energy from solar energy through DC/AC [19]. HP generally uses AC or alternating current to drive HP machines. Several studies also use direct current / DC in driving HP machines [20]. The photovoltaic heat pump (PV-HP) system is promising in terms of overall energy conversion efficiency [21].

PV technology can directly convert solar energy into electricity as long as sufficient sunlight is available and can be combined with heat pumps. Photovoltaic Assisted Heat Pump (PVA-HP) combines PV technology and Heat Pump technology. PV technology assists Heat Pump technology in generating electrical energy, while the heat source is derived from the air. Roofs, windows, and other structures are often integrated with various technologies. Combining photovoltaic systems with buildings is commonly known as photovoltaic integration, and it is aimed at saving installation space [28, 29]. PVA-HP technology has the capability to manufacture water heaters, air heaters, and coolers. Additionally, it can supply electricity to buildings, which is its most significant feature. PVA-HP technology can be produced in on-grid or off-grid forms, utilizing conventional electricity networks. The surplus electricity PV systems generate during bright daylight can be exported to conventional power grids. This capability can help to balance the energy supply and demand [30].

Researchers often evaluate the performance of the PVA-HP system by analyzing its energy output. The researchers compared the results of their study with previous research conducted on the proposed system. For instance, in reference [31], a comparison was made between the performance of a heat pump with solar cooling using photovoltaic technology and that of a heat pump with PVT systems using flat plate collectors. They individually compared the performance of HP systems with both PV technology and PVT technology. The comparison is being made for space heating applications. Manzolini et al. [32] presented a simulation approach for enhancing HP performance using PV modules in 2016 [32]. This study compares the energy performance outcomes of conventional HP systems and photovoltaic (PV) assisted modules. The simulation methodology is implemented through the utilization of Matlab and TRNSYS software. The application is intended for the roof of a detached structure featuring two compartments. The first scenario involves the utilization of PV modules assisted-HP, while the alternative scenario employs a conventional system without integrating PV modules. The comparative analysis reveals that incorporating PV modules in simulations yields more favorable results than conventional or without PV assistance. Bellos et al. have designed HP technology that utilizes photovoltaics to heat a room [31].

Ji et al. has presented a modeling or simulation approach to describe the Photovoltaic Thermal Assisted Heat Pump (PVTA-HP) technology's single source system for warm water production [33]. The modeling methodology is employed to evaluate the temperature distribution within the system, specifically from the perspective of the evaporator temperature. Subsequently, other researchers have utilized the model mentioned above to enhance the efficacy of PVT collectors in actual weather conditions in Hong Kong [34] and Tibet [35]. Zhang et al. [36] have developed a new PVT-assisted heat pump technology for the current generation. The proposed model utilizes a PVT system in conjunction with a loop-heat-pipe collector to facilitate domestic hot water production. The previously mentioned loop heat pipe model serves as a PVT collector. The collector can operate in both direct and indirect assisted modes. The Direct Assisted Mode exhibits a comparatively higher average Coefficient of Performance (COP) level than the Loop Heat Pipe Mode, which lacks a coupled heat pump.

Zhou et al. [37] designed the PVT hybrid collector micro-channel system with HP and evaluated its performance. The performance results of HP and PVT indicate warm water with a COP reaching 4.7. Approach The experiment was conducted in the northern region of China. Similarly, the numerical approach to system optimization has been discussed previously [38]. The PVT-HP system exhibits a thermal efficiency of 59.7% and an electrical efficiency of 14.5%. According to study of Zhou et al. [39], the COP value exceeds 5.2. Liang et al. [40] have integrated a PVT system featuring vented microchannels. In experimental tests, the direct expansion system has demonstrated the ability to produce hot water and achieve a commendable COP level.

Ji et al. [33] have reported on enhancing the PVT system's performance using HP in parallel during cloudy weather conditions or low radiation. The system above can fulfill the requirements for space heating and domestic hot water during periods of suboptimal solar intensity. This system operates in conjunction between the evaporator and PVT. Fang et al. [41] conducted experimental research to investigate the production of Solar Cooling (SC), Solar Heating (SH), and Domestic Hot Water (DHW) under various operational conditions. The energy produced by the Photovoltaic Thermal (PVT) collector can be utilized to supply space heating (SH) and domestic hot water (DHW). In order to supply domestic hot water, the energy obtained from the Solar Collector is utilized and subsequently released. The methodology employed for assessing the efficacy of this system is a suitable mathematical approach [41].

Fu et al. [42] evaluated a heat pump system that utilizes an air-cooled heat exchanger (HE) parallel to PVT technology featuring a heat pipe collector. The utilization of heat dissipation in a PVT system with heat pipes results in the production of hot water. An experimental approach was utilized to test a comparable system, as demonstrated by Li and Sun's testing of analog systems [43]. The system comprises a PVT integrated with a Loop Heat Pipe (LHP) featuring an aerial heat source. The TRNSYS program optimized water heaters by simulating the PVT and Heat Pump (HP) combination [44]. The integration of two PVT systems and a Heat Pump can facilitate the production of hot water through the utilization of solar energy at varying intensities. Yao et al. reported the development of a hybrid system consisting of PVT-HP and a direct borehole heat exchanger [45]. This system is designed to heat water using one or two sources.

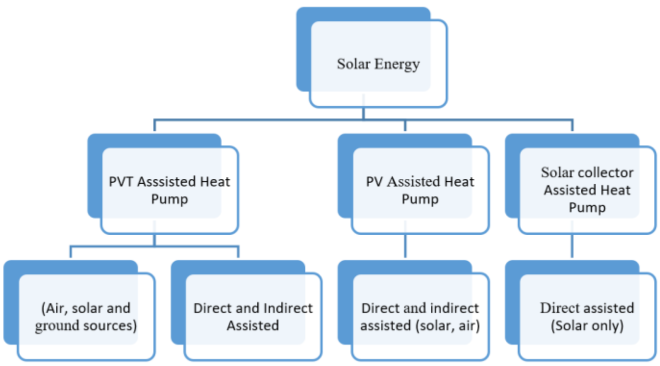

Figure 1. Conceptual scheme of solar energy-assisted heat pump

3. MATHEMATICAL MODELLING

3.1 Solar-assisted heat pump water heater with micro-channel heat transfer

For water heaters combined with solar-assisted heat pumps, implementing R290 and mini canal collectors of heat pumps have been studied by Kong et al. [46]. During the winter, the following parameters were measured: maximum solar intensity of 592 W/m^2, wind speed ranging from 0.01 to 1.15 m/s, and ambient temperature ranging from -3.0℃ to 12.2℃. A volume of 200 liters of water is heated to a temperature range of 37.7-54.9℃. Applying R290 with direct assistance for the heat pump investigated the average COP performance. The COP efficiency average is as follows.

The average Thermal performance in this system is:

$$Q_{c.avarage} = M_w C_{p.w} \frac{(t_{w,final} - t_{w,initial})}{\tau}$$

where, M_w is the total mass of water in the tank, $C_{p,w}$ is the isobaric specific heat of the water, the heating time is τ, the initial and final water temperature is $t_{w,initial}$ and $t_{w,final}$ respectively.

The instantaneous system COP is defined as follows:

$$COP_i = \frac{M_w C_{p.w}(t_{w,final} - t_{w,initial})}{\tau_i W_{com,i}}$$

where, power electricity for the compressor $W_{com,i}$, the time step is i, the length of the time step is τ_iThe number of time steps during the occupied process is L.

The $COP_{average}$ is the average system COP as follows:

$$COP_{average} = \frac{M_w C_{p.w}(t_{w,final} - t_{w,initial})}{\sum_{i=1}^{L} \tau_i W_{com,i}}$$

where, the efficiency average of the collector η_{col_avg} is:

$$\eta_{col\_avg} = \frac{\sum_{i=1}^{L} m_{r.i}(h_{col,out} - h_{col\_in})}{\sum_{i=1}^{L} A_{col} I_{T,i}}$$

3.2 Solar-assisted heat pumps integrated heating system

For cold weather, the integration of solar energy and heat pump technology has been designed by Qiu et al. [47]. This study focuses on the utilization of solar energy at medium temperatures. A solar collector has been installed in conjunction with a two-stage compression heat pump system. This system comprises three distinct temperature ratios, which are low, medium, and high temperatures.

The new integration reached a maximum performance of 55% higher than the two existing system types. The outdoor temperature system is up to -25℃.

For the mass flow model with the first point compressor as the following:

$$m_1 = (0.109 + 0.00305T_e - 0.000253T_m - 0.00000194T_m^2)\frac{f_1 - 2.857}{60 - 2.857}$$

For compressor power consumption model of the first-pint compressor is as follows:

$$w_1 = (2.13 + 0.02T_e + 0.013T_m + 0.0009T_m^2)\frac{f_1 + 2.2}{60 + 2.2}$$

For the mass flow of the second-stage compressor is as follows:

$$m_2 = (0.045 + 0.00149T_m - 0.000072T_c - 0.000000208T_c^2)\frac{f_2}{50}$$

For the compressor power consumption model of the second-stage compressor:

$$w_2 = (2.98 + 0.000886T_m - 0.00064T_c + 0.000044T_c^2)\frac{f_2}{50}$$

For the grade of a superheating variable to adapt the results in study [48].

$$m'_2 = \left[1 + F_v\left(\frac{v}{v'} - 1\right)\right] m_2$$

$$m'_2 = \left(\frac{m'_2}{m_2}\right)\left(\frac{\Delta h'}{\Delta h}\right) w_2$$

For the condenser model, the heat exchanger capacity of the condenser was calculated as follows:

$$Q_c = m_2(h_{2o} - h_c)$$

Model of the expansion valve:

The heat exchange capacity of the economizer was calculated as follows:

$$Q_{eco} = m_1(h_c - h_{eco}) \times 100$$

For the evaporator model, the heat exchange capacity of the evaporator Q_e was calculated as follows:

$$Q_e = m_e(h_e - h_{eco})$$

The evaporator model should consider the difference between evaporating and outdoor temperatures. The evaporating temperature was calculated as follows:

$$T_e = T_o - \frac{Q_e}{A_e K}$$

For the flat-plate solar collectors model, the heat collecting capacity Q_{sol} and the efficiency η is calculated as follows:

$$Q_{sol} = I\eta A_{sol}$$

$$\eta = 0.77 - 4.47\left(\frac{T_{sol} - T_o}{I}\right)$$

The heat exchange capacity of economizer Q_{eco} was calculated and the intermediate branch mass flow m_{sol} is calculated as:

$$m_{sol} = \frac{Q_{eco}}{(h_{mid} - h_c) \times 100}$$

The refrigerant mass flow of the first-stage compressor m1 was calculated as follows:

$$m_{sol} = m_2 - m_{sol}$$

For the total power consumption of the two compressors, w was calculated as follows:

$$w = \frac{Q_g}{COP}$$

For the heat output, Q_g was calculated as follows:

$$Q_g = Q_c + Q_{sol}$$

3.3 Direct-expansion solar-assisted heat pump for water heater

Experimental performance analysis of a direct-expansion solar-assisted heat pump water heater with R134a in summer [49]. The experimental testing of this system was conducted to provide warm water. The utilized collector is a flat plate collector with a surface area of 2.1 square meters. The study employed a rotational-type airtight compressor. The experiment was conducted under a solar intensity range of 285-634 W/m^2. The compressor speed ranges from 2,500 to 6,000 rpm. The water temperature has been elevated from 50-60.3℃.

For the thermal heat gain at the microchannel $Q_{w,m}$ to the hot water in the tank by the condenser as follows:

$$Q_{w,m} = Q_{wCp,w}\frac{(t_{final} - t_{initial})}{\tau}$$

For the average coefficient of performance, as defined, is COP_{avg}. Which τ is the heating time when the initial time and final time as t_{final} and $t_{initial}$ respectively. τ_j is the step of time, $W_{compressor,j}$ is *the* power of the compressor in the j-time step.

$$COP_{avg} = \frac{MwCp,w(t_{final} - t_{initial})}{\sum_{j=1}^{k} \tau_j W_{compressor,j}}$$

For the performance of the instantaneous coefficient to the indirect Solar Air heat pump COP_j is defined as:

$$COP_j = \frac{M_w C_p, w\Delta t_{w,j}}{\tau_j W_{compressor,j}}$$

where, $\Delta t_{w,j}$ is the water temperature lift of the j^{th} time step.

3.4 Hybrid PVT heat Pump systems for heating and cooling

Ramos et al. [50] have designed PVT technology and heat pump for room cooling, heating, and power in a town setting. Techno-economic analyses have been conducted on integrating photovoltaic-thermal systems with heat pumps. The study utilized a simulation or modeling methodology within the TRANSYS framework. The designated locations for the yearly simulation are Seville, Madrid, Rome, and Bucharest. The optimal configuration for the simulation outcomes entails incorporating PVT technology into a water-to-water heat pump system, utilizing fluid as the working medium. The simulated area of the house is 100 m^2. The roof area measures approximately 50 m^2 and can accommodate 4 to 5 occupants. The PVT technology enclosed more than 60% of room heating and more than 50% of the demand room cooling.

For the PVT and HP technology, thermal efficiency using flat-plate collectors is

$$\eta_{TH} = F_R(\tau\alpha) - F_R U'_L\left(\frac{Tin - Ta}{I}\right)$$

For the loss coefficient U_L in the temperature $(T_{in} - T_a)$

$$U'_L = U + U_L(T_{in} - T_a)$$

For the heat removal efficiency factor of the overall collector F_R

$$F_R(\tau\alpha) = F_m(\tau\alpha) - \left(\frac{mCp}{m_{test}Cp + \frac{F_m U'_L}{2}}\right)$$

For efficiency of photovoltaics is

$$\eta_{PV} = \frac{P_{electric}}{IA}$$
$$\eta_{PV} = \eta_0[1 - \beta(T_{PV} - T_{PVo})]$$

For the energy balance of fluid streams flowing up and down

$$M_{iCp}\frac{dT_i}{dt} = \alpha_i m_h c_p(T_h - T_i) + \beta_i m_L c_p(T_L - T_i) + UA_i(T_a - T_i) + \gamma_i c_p \sum_{i=1}^{N}(T_i - T_i) + Q_i$$

3.5 Photovoltaic thermal assisted heat pump for a water heater with real-time switch

Research on a real-time integrated control method of Photovoltaic and heat pump have been designed by Li et al. [51]. The objective of this control system is to regulate the temperature of warm water in real-time in order to optimize energy consumption during the heating process. The heat collector's surface area measures 4.32 $m^{2,}$ and the compressor employed is R22. The quantity of heated water amounts to approximately 150 liters. The experimental approach was utilized to test the simulation results or mathematical models in Nanjing City.

For the heat balance equation of PVT technology with a collector as:

$$Q_s = Q_c + Q_{pv} + Q_{con} + Q_{rad}$$

For the energy absorbed by refrigerant as

$$Q_s = E_s A_c\left[\tau_g(\alpha - \beta\eta_{PV}) - U_L\left(T_p - T_a\right)\right]$$

For the heat loss coefficient of PVT technology U_L as

$$Q_L = U_L(T_p - T_a)A_c$$
$$U_L = \left(\frac{1}{h_{con}+h_{rad}} + \frac{1}{h_{pv-g}} - \frac{Q_e}{Q_L h_{pv-p}}\right)^{-1}$$

For the heat transfer equation of radiative h_{rad} and convective h_{con} as follows:

$$h_{con} = 2.8 + 3.0u_w$$
$$h_{rad} = 4\varepsilon_g\sigma\left(\frac{T_g+0.0552T_a^{1.5}}{2}\right)$$

For the photovoltaic efficiency equation η_{pv} with changing temperatures as follows:

$$\eta_{pv} = \eta_{pv}\left[1 + \eta_o\left(T_{pv} - 25\right)\right]$$
$$T_{pv} = T_g + \frac{Q_{con}+Q_{rad}}{A_c T_{pv,g}}$$

For the heat transfer convection of the evaporation tube:

$$\eta_{pv} = 3X_{tt}^{-2/3}h_1$$

where, h_1 is the coefficient of heat transfer for liquid-phase refrigerant as:

$$h_1 = 0.023Re_1^{0.8}Pr_1^{0.4}\lambda_1/d_{in}$$

For the coefficient of average heat transfer in two-phase regions of refrigerant as:

$$h_1 = \int_{xi}^{1} dx / \int_{xi}^{1}\frac{1}{h_{tp}(x)}dx$$

For the coefficient of heat transfer for refrigerant in the superheating region as:

$$h_{gr} = \frac{\lambda_1}{d_{in}}\cdot\frac{\left(f/_8\right)Re_v Pr_v}{1.07+12.7\left(\frac{f}{8}\right)^{0.5}\left(Pr_v^{\frac{2}{3}}-1\right)}$$

where, the turbulence friction on the Reynold number as:

$$f = (1.82\ lgRe_v - 1.64)^{-2}$$

The energy equal equation for the stored hot water by the refrigerant is:

$$Q_k = m_r\left(h_{c,i} - h_{c,o}\right) = c_p m_w \Delta t_w$$

For mass flow m_r of refrigerant in the compressor as:

$$m_r = \lambda r_0 V_g f/(60v_{suc}f_0)$$

For the power consumption of the compressor is:

$$W_{compressor}$$
$$W_{compressor} = m_r(h_{dis} - h_{suc})/(\eta_i\eta_m\eta_{mt})$$

For the coefficient of performance (COP) system is calculated as follows:

$$COP = Q_k/W_{compressor}$$

3.6 PVT heat pump system on refrigeration mode

The combination of PVT technology with a heat pump has been designed by Liang et al. [52]. An experimental approach for electricity, cooling, and heating application evaluated this design. The system mentioned above can generate heat, electrical, and cooling for the designated space. The present system comprises a direct expansion heat pump system. The RB-PVT technology can function as an evaporator during the heating process and as a condenser during cooling.

For the capacity of cumulative refrigeration is:

$$Q_c = m_r\left(h_{r,o} - h_{r,i}\right) = A_r\alpha_r(T_w - T_r)$$

For the coefficient of performance COP_r for the refrigerant can be calculated:

$$COP_c = \frac{Q_c}{P_{c,comp}} = \frac{\alpha_r A_r(T_w-T_r)}{Pc_{,comp}}$$

The power compressor and cooling power were equal to the total heat debauchery power as follows:

$$Q_h + Q_p = Q_c + P_{c,comp}$$

where, the heat debauchery Q_h from the shell of the heat pump unit as following:

$$Q_h = A_h(T_h - T_a) + \varepsilon\sigma A_h(T_h^4 - T_a^4)$$

For the ratio of the unbalanced system is as follows:

$$Q_h = \frac{Q_h + Q_h - Q_h}{P_{c,comp}}$$

4. CONCLUSIONS

Integrating Heat Pump technology with Solar collector Technology, Photovoltaic (PV) Technology, and Photovoltaic Thermal (PVT) Technology presents an intriguing opportunity for review and development. The energy performance of a heat pump can be improved by integrating it with a solar collector, PV, and PVT. This integration results in better overall energy performance than air and water sources without integration. The integration of heat pumps with PV, PVT, and solar collectors has the potential to enhance the performance of both systems, as evidenced by improvements in COP and efficiency. The conceptual diagram depicting the integration of heat pump technology with solar collector, PV, and PVT technology elucidates the existence of both direct and indirect modes of assistance or expansion processes. The heat or energy sources are from air, solar, and ground sources. This paper has reviewed a comparison of the model of direct assistance, indirect, level of coefficient of performance, and heat source of assistance in producing product applications. With an understanding of efficiency, COP and configuration models are taken into consideration for readers in developing and using heat pump technology. Aspects of the mathematical model are very important for predicting the performance results of heat pump systems combined with solar collectors, PV, and PVT technology. Thus, this paper can contribute to the development of future heat pump technology.

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