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Thermal analysis of PVT-HEX system: Electricity Efficiency and Air Conditioning System

Mohammad Amin Sarlak[a], Somayeh Davoodabadi Farahani[b,*],Mahdi Alibeigi[c]

[a,b]*Department of Mechanical Engineering, Arak University of Technology, Arak 38181-46763, Iran*

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Abstract

In this paper, a combined PVT-heat exchanger cycle with the aim of cooling the PVT system and supplying the required air of an air-conditioning system in comfortable conditions is investigated. The effect of weather conditions (radiation intensity and ambient temperature) on the electrical efficiency of PVT system and reduction of carbon dioxide emissions has been investigated. For this purpose, several cities in Iran with different climates have been considered. The results show that the electrical efficiency of PVT system increases by5% in winter and 8% in summer. About 86% of the generated electricity is stored while the electrical energy required by the fan and pump and the cooling and heating energy of the building are supplied. The city of Tabriz has the highest electrical efficiency of about 0.1622. Carbon dioxide emissions were also calculated. The use of the proposed hybrid system can be effective in reducing the emission of pollutants.

Keywords: Thermal analysis; Thermal performance; PVT-HEX; air condition system, emission

1. Introduction

In order to deal with the rapid growth of electricity demand and to prevent the destructive environmental problems caused by the use of fossil fuels, many efforts have been made to develop the use of renewable energy. Solar power supply methods are generally divided into two categories [1, 2].Thermal systems that indirectly convert the sun's thermal energy into electrical energy, and photovoltaic systems in which the sun's radiant energy is converted directly into electrical energy. Photovoltaic cells are high-efficiency converters that their efficiency decreases under the influence of heat and as the operating temperature rises.

One of the methods to reduce the power drop due to rising cell temperature is the use of a combined photovoltaic-thermal system. Thermal photovoltaic(PVT) systems around photovoltaic cells recover lost thermal energy. This type of system is a combination of photovoltaic system and solar heating system Which simultaneously generates heat and solar electricity. In this type of energy system, while making optimal use of the installation space, it is possible to increase the efficiency of the photovoltaic module. The operating fluid in this type of system can include water, air and air / water combined fluid[3]. Various parameters including climatic, geometric, thermodynamic, optical and operational parameters affect the energy produced by the PVTsystem. By parametric analysis of the system, the effect of parameter changes can be investigated and by performing optimization, the desired system can be properly designed.

Appeared. In a 2007 study, the effect of two parameters of glass coating permeability and compression coefficient was investigated. In this research, the PVTsystem with rectangular channels was modeled with mathematical relations. Based on the results of this study, the thermal-electrical efficiency increased with increasing the transmission coefficient of glass coating. Also with increasing compression ratio, area The coverage by the cells increases and thus the amount of electrical energy produced by the panel increases by 79% but its efficiency changes slightly [4]. In another study, the header-riser model PVT system was simulated with mathematical relations and then the effect of changes in water flow rate, collector length and collector plate temperature was evaluated. The results show that with increasing flow and collector length, overall efficiency increased and with increasing collector temperature, overall efficiency decreased. In this study, changes in these parameters on exergy efficiency were also investigated. By increasing the discharge and collector length, the optimal point for exergy efficiency was obtained. At a flow rate of 0.006 kg / s and a length of 2 m, the exergy efficiency reached a maximum, but with the increase of the collector temperature, the exergy efficiency also decreased [5].The sample performance of the cold water PVT system was investigated analytically. The evaluated system had rectangular channels. According to the energy balance equations in PVT layers, its functional parameters such as PV efficiency, solar cell temperature, outlet water temperature and useful heat receipts were calculated. Then, the effect of inlet water temperature changes, number of PVT modules and water flow rate on performance parameters was investigated. The results show that the inlet water with lower temperature, higher mass flow rate and less number of PVT modules led to higher electrical efficiency [6]. In order to optimize, an example of PVT system Cold water was simulated. In this research, system analysis was performed based on the second law of thermodynamics. Then, the effect of inlet water temperature changes on thermal and electrical performance was evaluated. Based on the exergy efficiency, the optimal value of inlet water temperature was obtained [7]

An example of a PVT water-cooled header-riser system using multi-objective function optimization (NSGAII) were reviewed. The parameters of mass flow, collector length, MATLAB software, air distance, storage tank volume and number of PVT modules were optimized in this study. Target functions included increasing heat efficiency, reducing pressure drop, reducing initial investment and reducing auxiliary heat source consumption [8].

Slimani et al.[9] compared the effect of weather conditions on the PVT system. Jakhar et al.[10] numerically examined the combined air-to-ground heat exchanger system and PVT and found that the combined system improved heating capacity and electrical efficiency. Hachchadi et al. [11] investigated the effect of cooling of PVT system by air. Panga et al. [12] experimentally investigated the thermal performance of a combined photovoltaic-thermoelectric system and found that the use of a heat sink behind the thermoelectric module thermally improved the performance of the system. Fisac et al. [13] experimentally evaluated the performance of a photovoltaic module for two independent modes in combination with thermoelectric generators. Their results show that with increasing temperature of photovoltaic modules, their efficiency decreases.Vishal et al. [14] optimized thermoelectric cooling for active cooling in a solar cell. The results of the experiment show that for the intensity of radiation at an efficiency of 0.8-1 kW / m^2 and at a temperature of 25 to 45 ° C, the electrical efficiency of the solar cell increases by about 8.1%. Mohammad Ali[15] studied the cooling methods of photovoltaic cells used in the last 5 years, such as nanofluids, the use of phase change materials, and based on the studies, it was concluded that PV / PCM systems due to the long payback period of up to 20 years,when working in a connection, become more expensive and less practical. Other research has been done on the use of phase change and nanofluidic materials to cool the photovoltaic system[16].

In the previous literature, it has been observed that many studies have been done on the composition of the PVT system and the supply of required air at a comfortable temperature. Therefore, in this study, the combination of heat exchanger-PVT to supply air with comfort conditions and improve electrical efficiency has been investigated. A water-to-air heat exchanger is used to transfer energy to and from water. It is used to cool the air entering the building during the summer and heat it in winter.The heat exchanger used in this research is of the fin tube type.PVT system is used to heat the air and bring the air temperature to comfortable conditions in winter and supply electricity to the ventilation system equipment such as pumps and fans.Several cities in Iran with different climatic conditions have been selected and the effect of climatic conditions (solar radiation intensity and ambient temperature) on the performance of the proposed system has been investigated.

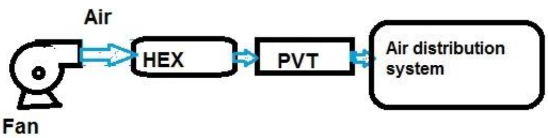

Figure 1 Schematic of the proposed system

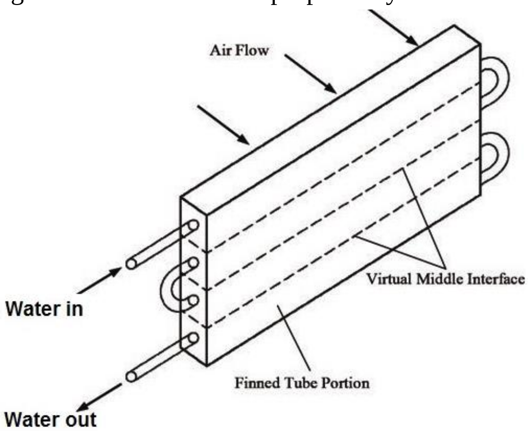

Figure 2 Schematic of the FinTube heat exchanger

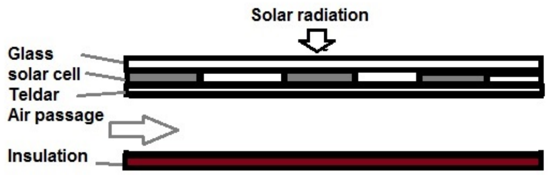

Figure 3 Schematic of the PVT system

1. Problem description

A schematic of the desired geometry is shown in Figure 1. In winter, the heat exchanger preheats the ambient air and, by passing through the piping system, finds the rest of its required heat and reaches the temperature of comfort conditions. In summer, the ambient air is cooled by a heat exchanger and cools it by passing through the PVT system and reaches the temperature of comfort conditions in summer. A schematic of the PVT system and the Fin Tube heat exchanger is shown in Figures 2 and 3, respectively. The comfort temperature[17] is considered to be 20 degrees Celsius in winter and 26 degrees Celsius in summer. The water inlet temperature is assumed to be 15 ° C to the heat exchanger. If the air temperature is lower than the inlet water temperature, the air will not pass through the heat exchanger. In summer, if the temperature of the air leaving the heat exchanger is less than the comfort temperature, it passes through the PVT system. To model the problem, heat transfer is assumed to be one-dimensional, radiant heat transfer is neglected, and the thermophysical properties of air and water are constant.

The dimensionless Parametric in this model for HEX (heat exchanger).

Reynolds number[18]:

$$\mathrm{Re} = V_m D / \upsilon \tag{1}$$

V_m is mean air velocity, D is External tube diameter and υ is kinematic viscosity.

The friction factor[18]:

$$f = 2\Delta p / \rho V_m{}^2 \tag{2}$$

Where, Δp is pressure drop of the finned tube bundles and ρ density of flow air [16].
The Nusselt number:

$$Nu = h.D / k \quad (3)$$

Which, h is convective heat transfer coefficient and k is thermal conductivity coefficient [16].

$$h = Q_{HEX} / \left(A_h \Delta T_{LMTD} \right) \quad (4)$$

Which, A_h is the heat transfer surface area. The potential of cooling in heat exchanger can be defined as[18];

$$Q_{HEX} = m_a Cp_a \Delta T_{HEX,out} \quad (5)$$

$$\Delta T_{HEX,out} = \left(T_{airout_{HEX}} - T_{amb} \right) \quad (6)$$

Where, m_a is the air mass flow rate, Cp_a is the specific heat rate capacity of air flow, $T_{airout_{HEX}}$ is the outlet temperature from

Heat exchanger (HEX) and T_{amb} is ambient temperature.
In PV-T air collector the gain heat rate for heating the fresh air can be calculate as;

$$Q_{PVT} = m_a Cp_a \Delta T_{PVT} \quad (7)$$

$$\Delta T_{PVT} = \left(T_{airout_{PVT}} - T_{amb} \right) \quad (8)$$

Where, $T_{airout_{PVT}}$ is the outlet temperature from PVT system. The required heat transfer in the PVT-fin system of this case which can be defined as

$$Q_h = m_a Cp_a \Delta T_w \quad (9)$$

$$\Delta T_w = \left(T_w - T_{amb} \right) \quad (10)$$

$$Q_c = m_a Cp_a \Delta T_s \quad (11)$$

$$\Delta T_s = \left(T_{amb} - T_s \right) \quad (12)$$

Where, Q_h is thermal power for heating, Q_c is thermal power for cooling of system, T_w is temperature of system in winter and T_s is system temperature in summer.The logarithmic mean temperature difference (LMTD) between the tube wall of system and the air can be assumed as [18]:

$$\Delta T_{LMTD} = \frac{\left(\Delta T_{HEX,s} - \Delta T_s \right)}{\ln\left(\frac{\Delta T_{HEX,s}}{\Delta T_s} \right)} \quad (13)$$

$$\Delta T_{HEX,s} = \left(T_{airout_{HEX}} - T_s \right) \quad (14)$$

Numerous Experimental estimation investigation for the Nusselt number and the friction factor has been presented in terms of calculation of average heat transfer coefficient and the pressure drop based on the geometric parameters of the finned tube bundles such as longitudinal and transverse pitches which in this study assumed the tube diameter.
According to the first law of thermodynamics was achieved for each component of the PVT air collector PV modules can be presented in following equation[18];

$$\tau_g \left[\alpha_c \beta + \alpha_c \left(1 - \beta \right) \right] I(t) wdx = \left[U_{T_{ca}} \left(T_c - T_{amb} \right) + U_T \left(T_c - T_{bs} \right) \right] wdx + \eta_c \tau_g \beta I(t) wdx \quad (15)$$

Also, the energy balance base on first law of thermodynamics of the flow air in tedlar presented as[18]:

$$U_T \left(T_C - T_{bs} \right) wdx = h_T \left(T_{bs} - T_f \right) wdx \quad (16)$$

The Nusselt number and friction factor have been presented in following equation[16].

$$f = 662.3561 \mathrm{Re}^{-0.6453} \left(S_T / D \right)^{-0.2801} \left(S_L / D \right)^{-0.3927} \quad (17)$$

$$Nu = 2.6653 \mathrm{Re}^{0.3175} \left(S_T / D \right)^{-0.8732} \left(S_L / D \right)^{-0.5618} \quad (18)$$

Electrical efficiency $\left(\eta_c \right)$ of PV modules can be written. [18, 19]

$$\eta_c = \eta_{STC} \left[1 - \beta_0 \left(T_c - T_{STC} \right) \right] \quad (19)$$

Electrical energy gain $\left(E_u\right)$,which generated by the PV panels can be defined as[18]:

$$E_u = \eta_c A_{tot,PVT} I(t) \quad (20)$$

PVT outlet air temperature can be express as following as

$$T_{airout,PVT} = \left[\frac{h_p(\alpha\tau)_{eff}\, I(t)}{U_L} + T_{amb}\right]\left[1 - \exp\left(-\frac{A_{tot,PVT}U_L}{m_a Cp_a}\right)\right] \quad (21)$$

$$+T_{fin}\exp\left(-\frac{A_{tot,PVT}U_L}{m_a Cp_a}\right)$$

$$h_p = \frac{h_i}{h_i + h_0}$$

$$A_{tot,PVT} = N \times w \times L$$

the temperature of the hot surface of base surface defined as T_{bs} [20]:

$$T_{bs} = \frac{h_{p1}(\alpha\tau)_{eff}\, I(t) + U_{tT}T_{amb} + h_f T_f}{U_{tT} + h_f} \quad (22)$$

$$(\alpha\tau)_{eff} = \tau_g\left[\alpha_c\beta + \alpha_T(1-\beta) - \eta_{STC}\beta\right] \quad (23)$$

The temperature of cell in PV system has been appraised as: [21]

$$T_C = \frac{\tau_g I(t)\left[\alpha_c\beta + \alpha_T(1-\beta) - \eta_{STC}\beta_{amb}\right] + U_{Tca}T_{amb} + U_T T_{bs}}{U_{Tca} + U_T} \quad (24)$$

Table 1. input parameters for the PTV-FinTube heat exchanger combined system.[22]

Parameters	Value
A_{tot_PVT}	$17m^2$
C_a	$1005 J/Kg.K$
D	$0.025m$
h_p	0.390
h_{p1}	0.375
h_{p2}	0.965
h_T	10.3 W/m/K
L	$1.2m$
m_a	$0.25kg/s$
m_w	$0.5kg/s$
N	26
N_{tub}	24
N_T	6
S_T	$0.0350m$
S_L	$0.0350m$
T_{STC}	$25°C$
U_L	$5.62\ W/m^2/K$
U_T	$66\ W/m^2/K$
U_{Tca}	$11.4\ W/m^2/K$
U_{tT}	$9.72\ W/m^2/K$
V	$0.5m/s$
w	$0.54m$
α_c	0.9
α_T	0.5
β	0.83
β_0	0.0045
η_{STC}	0.15
τ_g	0.95
ρ	$1.217kg/m^3$

2. Results & Discussion

In this study, using thermal modeling presented for PVT-FinTube heat exchanger combined system, the effect of environmental conditions and radiation intensity have been investigated. Table 1 shows the input parameters for the PTV-Fin Tube heat exchanger combined system. First, to check the accuracy of the proposed modeling, the results in the case without heat exchanger are compared with reference [22]. For ambient temperature and radiation intensity, the data given in the reference are used. Figure 4 shows the temperature of the solar cell, the temperature of the hot surface of base surface and the efficiency of the electrical system. There is less than 8% error between the results of the present study and the results of Hachchadi et al.[22]. Then, using the proposed hybrid system in the present study, the electrical efficiency of the photovoltaic system using cool air in December and July has been investigated and shown in Figure 5. The results show that about 5-8% of the electrical efficiency has been increased using the hybrid system compared to the PVT system. Cooling the PVT system increased electrical efficiency by about 8% in July. The results also show that during the day, with the approach of 12 o'clock (noon), the ambient temperature and radiation intensity have increased and the electrical efficiency is minimal at this time. The heat exchanger heat and the heat obtained from the PVT system are shown in Figure 6.

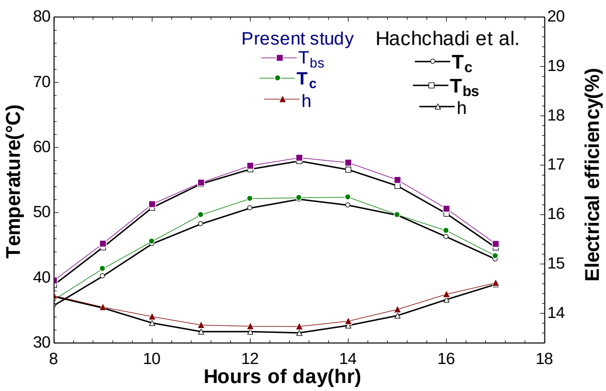

Figure 4 Comparison of results with previous literature[22]

a)
b)

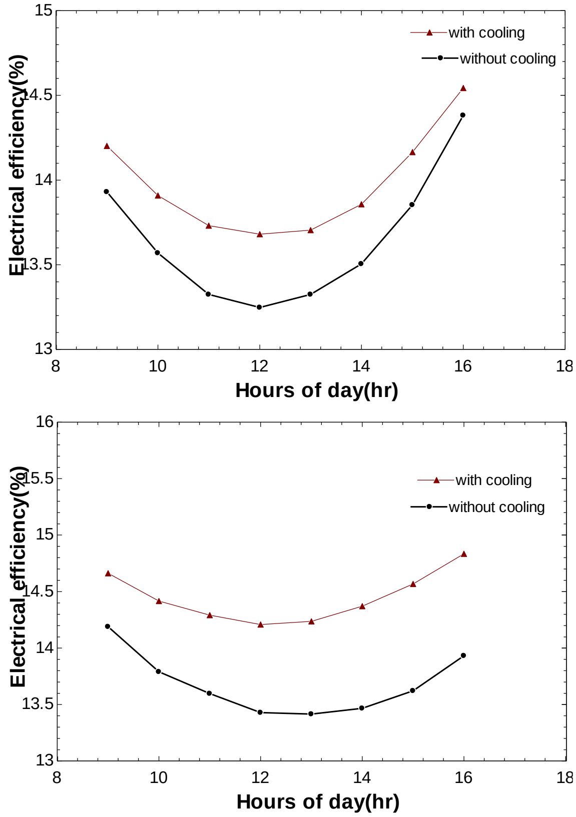

Figure 5 Effect of cooling on electrical efficiency in a) December, and b) July

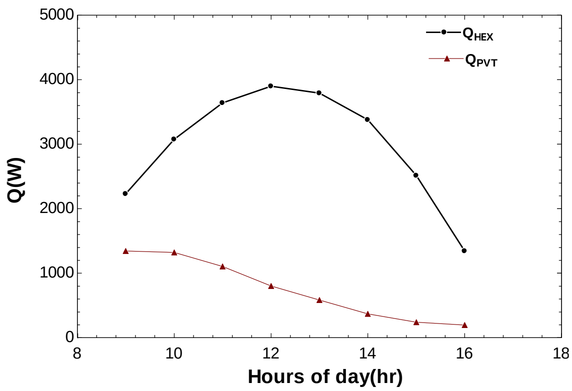

Figure 6 Heat received from PVT system and heat exchanger

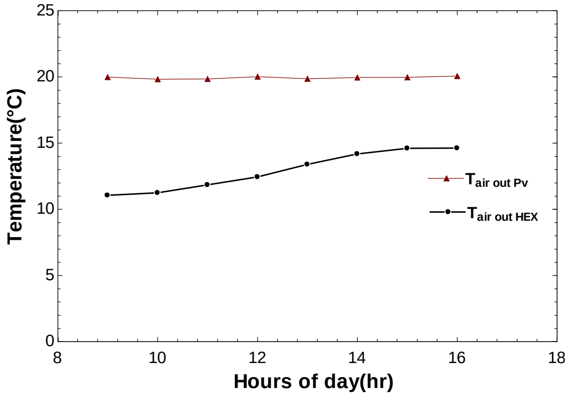

Figure 7 Exhaust air temperature from PVT system and heat exchanger

It is observed in the early times that the amount of heat of the heat exchanger is high because of the low radiation. The heat supply from the PVT system changes according to the radiation intensity and decreases with increasing radiation intensity through the heat exchanger. Figure 7 shows the electrical efficiency of PVT system with and without cooling in winter, which has increased the average electrical efficiency by about 4% using the proposed system in this study.

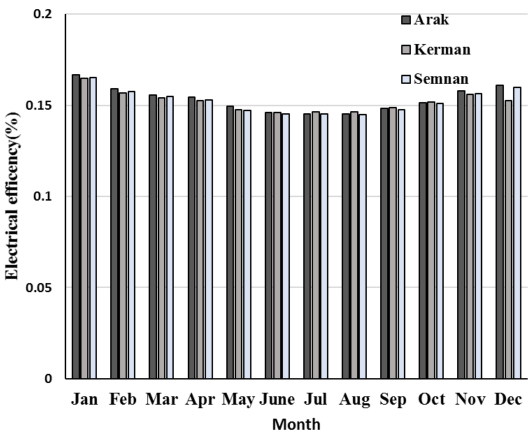

Figure 8 Electrical efficiency for each month of the year

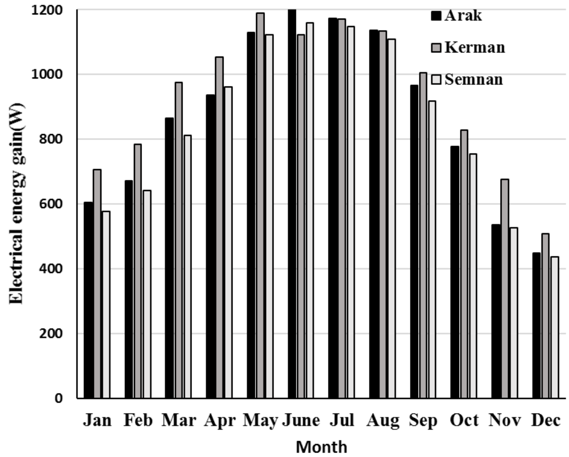

Figure 9 Electrical energy gain for each month of the year

In the following, using meteorological information, several cities in different climates in Iran[23] are considered. These cities have different intensities of radiation and temperatures depending on different climatic conditions. Using the Carrier software, the cooling and heating load required for the building has been calculated according to the climatic conditions of the city and this issue has been taken into account. The comfort temperature is fixed for all cities. The amount of electrical efficiency and interest of electrical energy from the proposed system in three cities of Kerman, Arak and Semnan in 12 months of the year has been studied and shown in Figures 8 and 9. The average annual electrical efficiency for the city of Arak, Kerman and Semnan is 0.153.0.151 and 0.152, of which Arak has the highest efficiency. The highest yields occurred in December and January the lowest yields occurred in July and August. The average annual electricity energy gain for Arak, Kerman and Semnan is 929.83, 870.8 and 847.163 watts, respectively, of which Kerman has the highest electricity energy gain. The highest yields occurred in January and May. Electrical efficiency and electrical energy gain in March, December, October and July for the cities of Kerman, Arak, Tabriz, Ahvaz, Semnan, Kerman, Yazd, Birjand and Shiraz are shown in Figures 10 and 11. Maximum electrical efficiency for all selected cities except Kerman happened in December and for the city of Kerman in March. The highest electrical efficiency of 0.1622 is related to the city of Tabriz. The city of Tabriz has a lower intensity of radiation and temperature than the cities of Kerman, Arak and Birjand. The interaction of radiation intensity and ambient temperature has increased the electrical efficiency of PVT system in this city.

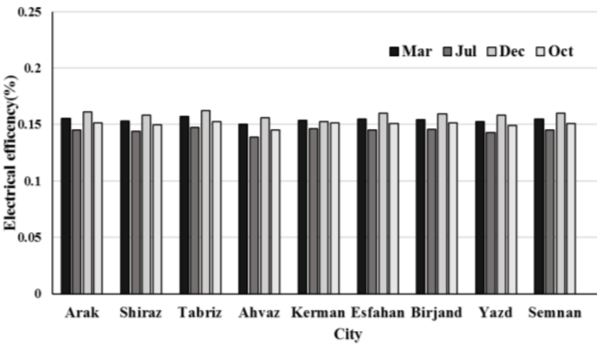

Figure 10 Electrical efficiency of the proposed system in selected cities

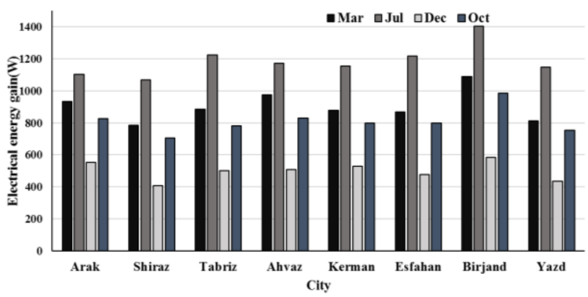

Figure 11 Electrical energy gain of the proposed system in selected cities

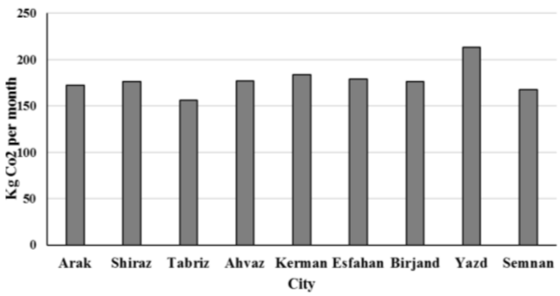

Figure12 Emissions of carbon dioxide in selected cities

The highest electricity energy gain is related to Birjand. Considering that about 14.7% of the electrical energy produced by the proposed system is used to power equipment such as pumps and fans, and the rest of the energy is stored, which can prevent the release of coke contaminants. The amount of carbon dioxide produced for the equivalent of energy saved from the combined heat exchanger-PVT system per year for different cities is calculated and shown in Figure 11. Figure 12 shows the reduction in carbon dioxide emissions per month using the proposed hybrid system. In fact, Figure 12 shows that the use of a combined PVT-heat exchanger system, in addition to providing air with a comfortable temperature, prevents the release of pollutants such as crane dioxide (Figure 12). Installing this system in Yazd can have a significant impact on the environment.

3. Conclusions

In this study, the PVT system - heat exchanger for cooling the PVT system and supplying air with a comfortable temperature for a 200 m^2 building has been investigated. Thermal modeling related to FinTube heat exchanger and PVT system has been performed. The area of the pipette is about 15 m^2 and the flow of supply air is equal to 0.25 kg/s. The electrical efficiency of the proposed system using cooling has increased by about 5-8% on average compared to the state without cooling. It was observed that the amount of energy gain produced in the PV system is proportional to the solar radiation. The amount of electrical efficiency and electrical energy gain from the proposed system in three cities of Kerman, Arak and Semnan has been studied in 12 months of the year. Birjand city has the highest electrical energy efficiency and Arak city has the highest electrical efficiency. About 86% of the electrical energy produced can be stored, which can reduce the emission of pollutants such as carbon dioxide. This study helps to select the best place to use the proposed hybrid system according to the goals of energy storage, increasing efficiency and reducing the emission of pollutants in the environment according to the weather conditions.

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