Proceedings

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International Conference on

RENEWABLE AND SUSTAINABLE ENERGY (ICRSE 2017)

April 12th & 13th 2017

Editors

Dr. M. Mohanraj

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Dr. J. Manikandan

Organized by

Department of Mechanical Engineering

Hindusthan College of Engineering and Technology

(An Autonomous Institution Affiliated to Anna University, Chennai)

(Accredited with 'A' Grade by NAAC)

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Preface

The continuous depletion of fossil fuel resources and its adverse environmental impacts on global climate puts forward great challenges for the research and development in the field of Energy Engineering and Technology. The concept of energy efficiency and its necessity needs to be explored. To full-fill the current social requirements and to meet the future energy demand, the Department of Mechanical Engineering, Hindusthan College of Engineering and Technology, Coimbatore has organized an International Conference on Renewable and Sustainable Energy 2017 to focus the recent research developments in the field of Renewable Energy Technology and to provide a plat form to disseminate the new developments and ideas to enhance the energy efficiency. We also invite renewable energy product manufacturers for exploiting their innovative products in conference exhibition. The outcome of this conference aims to bring the researchers, engineers, industrial experts, scientists and research scholars in the sphere of technical interests. This proceeding contain two abstracts of keynote address, forty technical papers published by the research scholars in the field of solar energy applications, thermal energy storage, bio-diesel energy, wind energy and the issues related to energy and the environment. We also thank the reviewers for their valuable review support for selecting the papers for the conference. Further, the selected papers of this conference will be published in Thermal Science: Scientific Journal.

We would like to be grateful to the Management of Hindusthan College of Engineering and Technology, Coimbatore for providing an opportunity to organize this event. We also express our gratitude to our Principal, Heads of Departments and faculty members for their kind support during every stages of the conference. Besides, we would like to thank all the authors for their value contributions to ICRSE2017. Further, the work contributions provided by all the supporting staffs are recognized. We also thank all the financial sponsors, for their financial support to make the conference a grant success. Moreover, the technical experts for their keynote address are highly acknowledged. The supports provided by student voluntaries are highly appreciated.

Editors

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Hindusthan College of Engineering and Technology (HICET) was started during the year 2000 by the industrialist and philanthropist, Thiru. T. S. R. Khannaiyann, Chairman, and Tmt. Sarasuwathy Khanniayann, Secretary. The institution is accredited by NAAC and National Board of Accreditation (NBA), New Delhi. HICET is spread over 120 acres and is located on Coimbatore-Pollachi Highways about 12 kms from Coimbatore Railway Junction. HICET has got autonomous status from the academic year 2016-17. HICET is currently offering following degree programs:

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PV THERMAL COOLING NUMERICAL MODELING WITH DIFFERENT WORKING FLUIDS

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A numerical model is proposed in this paper to evaluate the energy performance parameters of photovoltaic-thermal hybrid evaporators. The energy performance parameters such as photovoltaic electrical efficiency, thermal efficiency of the evaporator, overall efficiency of photovoltaic-thermal evaporators, solar energy absorption ratio and evaporator heat gain were predicted for the meteorological conditions of Almaty city in Republic of Kazakhstan. During simulation different working fluids (R134a, R407C, etc.) have been used. The ambient temperature was simulated in the range between -20°C and 30°C with solar intensity in the range from 100 W/m^2 to 900 W/m^2. The energy performance parameters under the influence of above ambient parameters are discussed. Numerical algorithm based on heat balance and conservation laws, computer program on C++ has been developed. The modelling results were also compared with experimental results reported in literature and found to be in good agreement with acceptable deviations.

Key words: *Photovoltaic-thermal (PV-T) hybrid system; Heat pumps; Cold climates; Kazakhstan*

INTRODUCTION

Theoretical and experimental investigations on hybrid photovoltaic-thermal systems have been performed by many researchers since 1970s [1]. One of the first works in this area is focused on using either air or water as the coolant of photovoltaic cells [2-3] and utilizing obtained heat in heat pumps. The basic idea of using a hybrid system is to simultaneously generate both electricity and heat. According to [1] the use of refrigerants as a coolant for photovoltaic cells is the most effective. At the same time, the hybrid PV-T solar collector system serves as an evaporator for the heat pump. Full reviews of recent researches on the use of hybrid PV-T absorbers with single-phase cooling in a flat plate solar collector are given in [4-7]. Solar collectors with a hybrid PV-T absorber with two-phase cooling applied to heat pumps are given in the works [1, 8-12]. For example, in [8] the system was comprised of independently developed flat plate solar PV-T collector based on micro-channel heat pipe and air source heat pump. Average COP of heat pump was 3.03, while overall system COP was 2.99. In [10] it was found that the novel PV/micro-channel-evaporator modules could achieve an average thermal, electrical and overall efficiency of 56.6%, 15.4% and 69.7% respectively, while system average COP reached 4.7. In [11-12] the energy performance parameters of heat pumps using a PV–T with circular and triangular tube evaporator configurations are compared. The results show that triangular tube PV–T evaporator configuration has enhanced the heat pump energy performance parameters such as, condenser heating capacity, COP and panel efficiency by 3%–7%, 3%–5% and 4%–13%, respectively when compared to the circular tube.

A numerical model is proposed in this paper to evaluate the energy performance parameters of PV-T hybrid evaporators. The energy performance parameters such as photovoltaic electrical efficiency, thermal efficiency of the evaporator, overall efficiency of photovoltaic-thermal evaporators, solar energy absorption ratio and evaporator heat gain were predicted for the meteorological conditions of Almaty city in Republic of Kazakhstan. During simulation different working fluids (R134a, R407C, etc.) have been used.

DESCRIPTION OF DIRECT EXPANSION SOLAR ASSISTED HEAT PUMP CYCLE

The detailed configuration of a direct expansion solar assisted heat pump and pressure-enthalpy diagram are shown in the Figure 1 and 2, respectively. The DXSAHP consists of a hermetically sealed reciprocating compressor, a water cooled condenser, a liquid receiver, a sealed type refrigerant drier, a sight glass, a thermostatic expansion device and a glazed solar collector integrated with PV modules, which acts as an evaporator. The geometric characteristics of the hybrid PV/T system have been taken in accordance with the [1]. The PV/T collector-evaporator is a hybrid solar collector with solar cell encapsulation laminated on to the front surface of a thermal absorber plate [1]. Evaporator's copper tube has 6 m length with 7 mm outer diameter and 6 mm inner diameter. A glass cover and a thermal insulation layer are provided. The solar PV/T collector (evaporator) was tilted to an angle of about 45^{o} with respect to horizontal [13]. The system is oriented to face south to maximize the solar radiation incident on the collector (evaporator). Kazakhstan is one of the leading countries in the Central Asian region with the average annual solar radiation potential. Annual duration of sunshine is 2200-3000 hours, and the estimated capacity of 1300-1700 kW per 1 m^2 per year, which exceeds that of Europe.

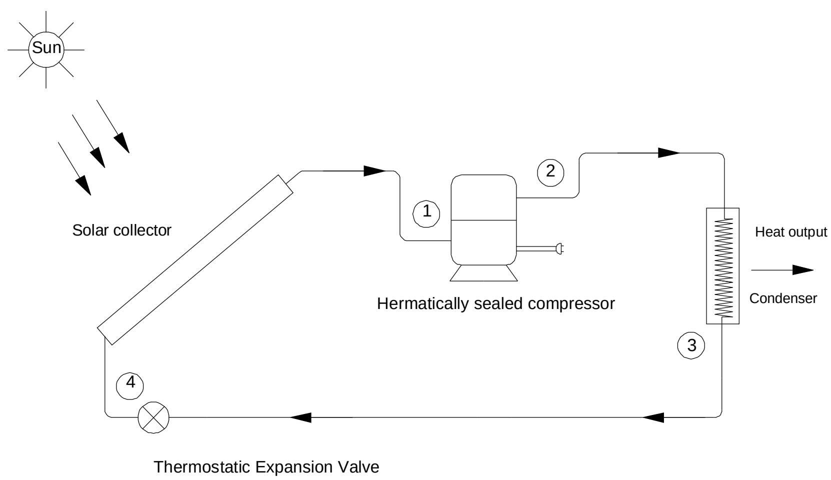


Fig. 1. Schematic diagram of a direct expansion solar assisted heat pump

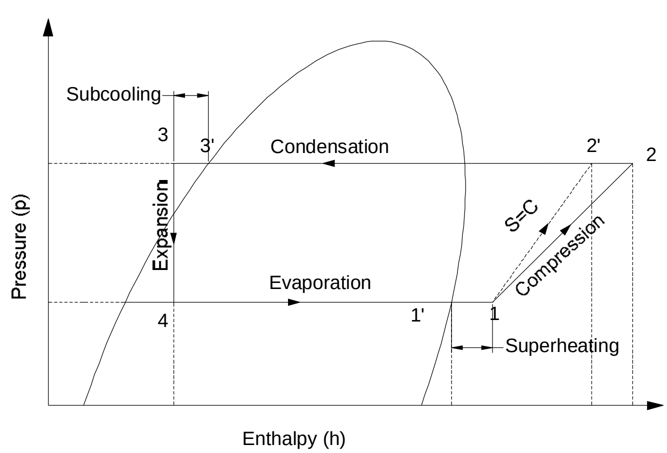


Fig. 2. Pressure enthalpy representation of a direct expansion solar assisted heat pump

MATHEMATICAL MODEL

The thermal performance of the PV-T system was numerically evaluated according to a mathematical model [1]. Heat balance equation of the PV module is:

$$
\begin{aligned}
l_{pv}\rho_{pv}C_{pv}\frac{\partial T_{pv}}{\partial t} &= G(\tau\beta)_{pv} - E + \alpha_{a-pv}\left(T_a - T_{pv}\right) + \\
&+ \alpha_{r,a-pv}\left(T_{sky} - T_{pv}\right) + \frac{T_c - T_{pv}}{R_{pv-c}}
\end{aligned}
\tag{1}
$$

where l_{pv}, ρ_{pv} and C_{pv} are, effective thickness, density and specific heat of the PV elements, respectively. R_{pv-c} is thermal resistance at the contact surface between PV elements and the thermal collector, λ_{pv} is the thermal conductivity of PV elements, α_{a-pv} and $\alpha_{r,a-pv}$ are coefficients of convective and radiant heat transfer between the PV elements and the environment, G is solar irradiance, $(\tau\beta)_{pv}$ the effective absorptivity of the PV elements; E is the output electricity of PV elements.

Two-dimensional equation of heat conduction of the heat collector is:

$$
\begin{aligned}
m_c C_c \frac{\partial T_c}{\partial t} &= G(\tau\beta)_c(1-\xi)A_c + \alpha_{a-c}(1-\xi)A_c\left(T_a - T_c\right) + \\
&+ \alpha_{r,a-c}(1-\xi)A_c\left(T_{sky} - T_c\right) + \xi A_c\frac{T_{pv} - T_c}{R_{pv-c}} + \alpha_r A_r\left(T_r - T_c\right) + \\
&+ A_c\frac{T_a - T_c}{R_b} + \lambda_{c,y}l_{c,y}A_c\frac{\partial^2 T_c}{\partial y^2} + \lambda_{c,z}l_{c,z}A_c\frac{\partial^2 T_c}{\partial z^2}
\end{aligned}
\tag{2}
$$

where R_b is the thermal resistance between the back side of the thermal collector and the environment, $(\tau\beta)_c$ is the effective absorptivity of heat collector, $l_{c,y}$ and $l_{c,z}$ are the effective thickness, ξ is the PV cell coverage ratio.

The simplified 1D conservation equations of the refrigerant flow in evaporator coil based on the laws of conservation of mass, momentum and energy. Continuity equation of the refrigerant:

$$
\frac{\partial\rho}{\partial t} + \frac{\partial(\rho u)}{\partial z} = 0 \tag{3}
$$

where ρ is the average density of the refrigerant, which is defined as

$$
\rho = \frac{\rho_v\rho_l}{\chi\rho_l + (1-\chi)\rho_v} \tag{4}
$$

where χ is the vapor quality that takes the value 1 in the superheated vapor, 0 in the subcooled liquid, and $0 < \chi < 1$ in the two-phase flow region.

Conservation of momentum is:

$$\frac{\partial(\rho u)}{\partial t}+\frac{\partial(\rho u^2)}{\partial z}=-\frac{\partial P}{\partial z}-\left(\frac{\partial p}{\partial z}\right)_f \tag{5}$$

where $\left(\frac{\partial p}{\partial z}\right)_f$ is the pressure drop of the refrigerant due to friction [1].

Energy conservation of refrigerant:

$$\frac{\partial(\rho h)}{\partial t}+\frac{\partial(\rho u h)}{\partial z}=\frac{\pi D_{in}}{A_p}\dot{q}_r \tag{6}$$

where $\dot{q}_r$ is the heat flux at the pipe wall, which is determined as $\dot{q}_r=\alpha_r(T_c-T_r)$; h is the average specific enthalpy of refrigerant, which is determined from the vapor quality and the specific enthalpy of saturated liquid and vapor, i.e.

$$h=\chi h_v+(1-\chi)h_l \tag{7}$$

NUMERICAL ALGORITHM

The above system of equations is solved numerically using the finite-difference method. First of all, initial conditions for temperature, pressure and vapor quality of refrigerant as well as temperature of PV cells and thermal collector are required. Input data as solar irradiance, ambient temperature, inlet physical properties of using materials and refrigerant mass flow rate are also necessary. Numerical algorithm based on heat balance and conservation laws is implemented on C++ computer program. All unknown parameters like heat transfer coefficients, heat flux, and frictional pressure loss were calculated according to papers [1,13].

RESULTS AND DISCUSSIONS

The energy performance parameters of PV-T hybrid evaporator such as, PV electrical efficiency, evaporator thermal efficiency, and solar energy input ratio and evaporator heat gain with different two-phase cooling fluid were numerically predicted for the meteorological conditions of Almaty, Kazakhstan. The available solar radiation data of Almaty city is presented in Figure 3.

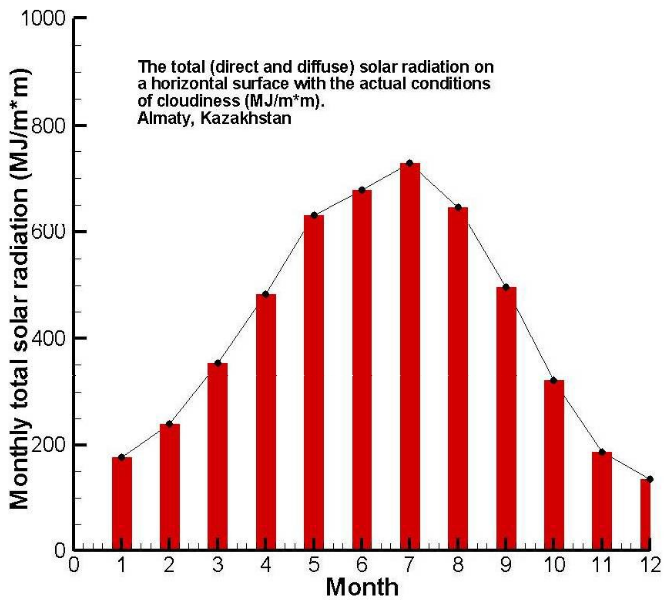


Fig. 3. The total solar radiation in Almaty city

Figure 3 shows sum of direct and diffuse solar radiation on a horizontal surface with the actual conditions of cloudiness in terms of MJ/m^2. According to this data daily average direct and diffuse solar radiation depending on environment temperature for typical day in each month in terms of W/m^2 were estimated. Figure 4 and 5 shows direct and diffuse solar radiation depending on ambient temperature, respectively.

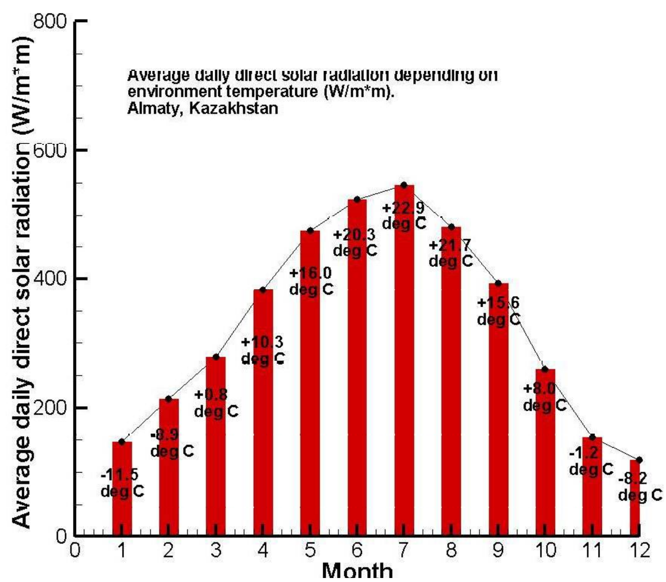


Fig. 4. The direct solar radiation in Almaty city

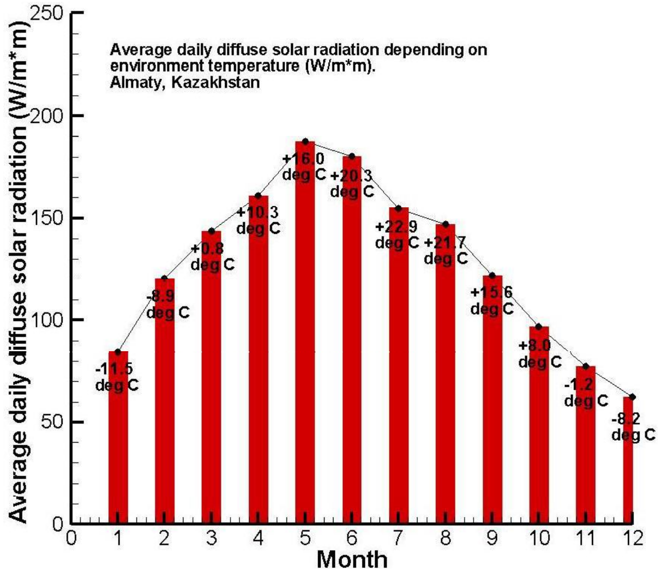
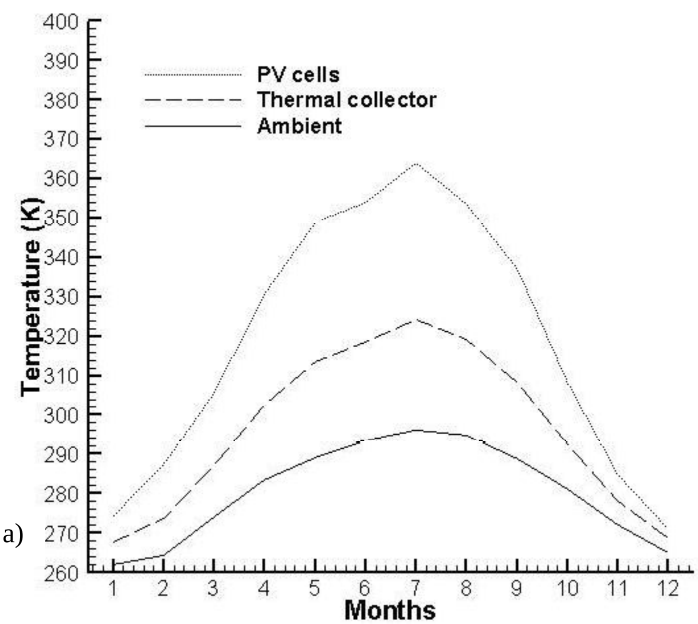
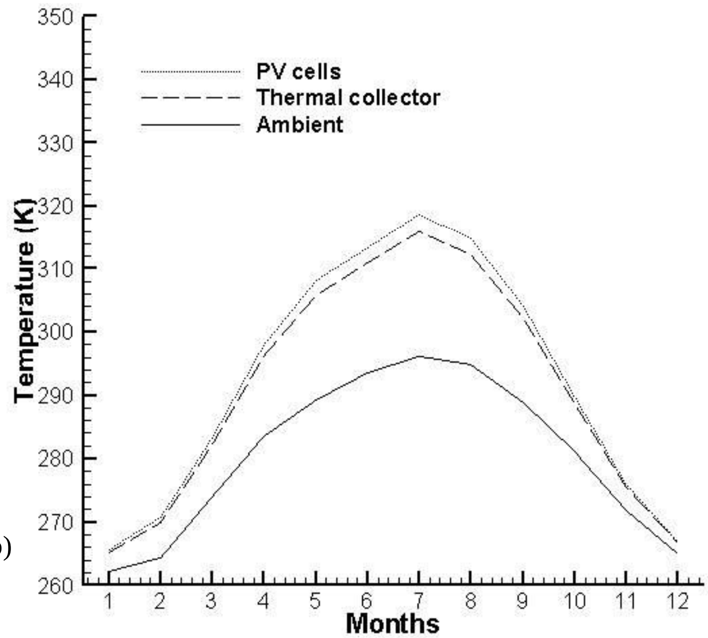


Fig. 5. The diffuse solar radiation in Almaty city

Figure 6 a) and b) shows the temperature distribution of PV elements depending on each month according to the system of equations (1) - (2) with and without thermal resistance between the PV cells and the evaporator.

a) 



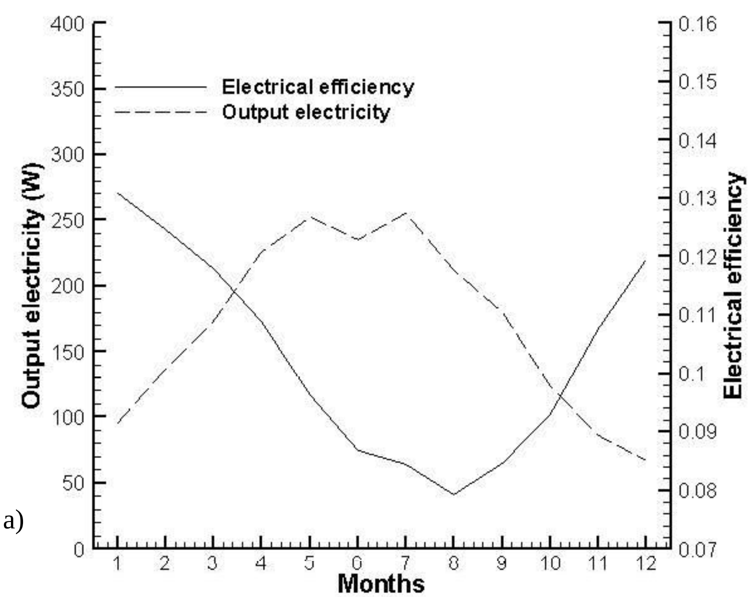
b)

a) - without the resistance, b) - with the resistance

Fig. 6 – The temperature distribution of PV cells and thermal collector (Almaty, Kazakhstan)

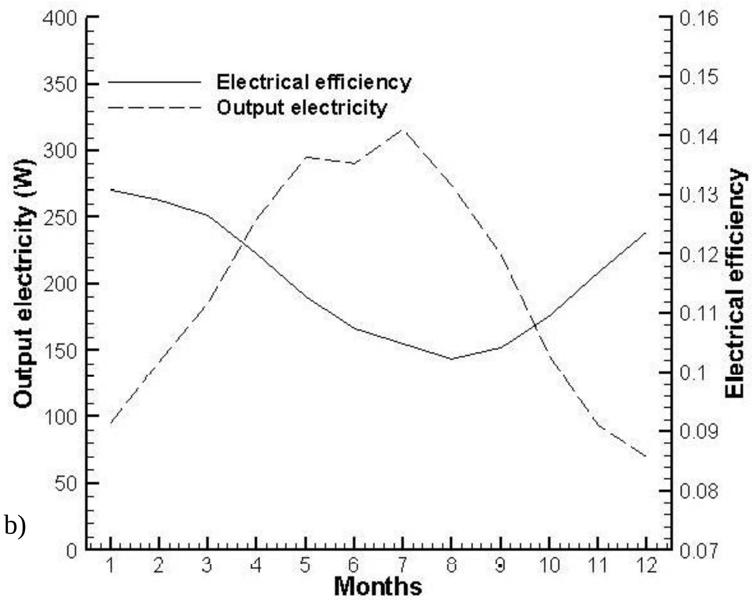
It follows from Fig. 6 that without including thermal resistance in equations (1)-(2) between PV cells and evaporator, the PV temperature reaches 364 K, whereas the evaporator temperature 324 K. Taking into account the resistance, the PV elements were cooled to 318.7 K, whereas the evaporator temperature became 315.86 K.

Figure 7 a) and b) shows the output electricity and PV efficiency of the PV elements in PV panel separately and hybrid PV-T collector, respectively.



a)

b)



a) – PV panel, b) – PV-T evaporator

Fig. 7 – The output electricity and electrical efficiency of PV cells (Almaty, Kazakhstan)

According to Fig.7 a) in a separate PV panel the maximum output electricity is 254.66 W, while efficiency of solar energy to electricity conversion 8.43%. In a hybrid PV-T system (Fig.7 b)), similar indicators are 316.68 W and 10.48, respectively. It follows that, by cooling the PV cells with a thermal absorber, more efficient output electricity is obtained.

The variation of evaporator heat gain with respect to different months with different two-phase cooling liquids (refrigerants) is shown in Fig.8.

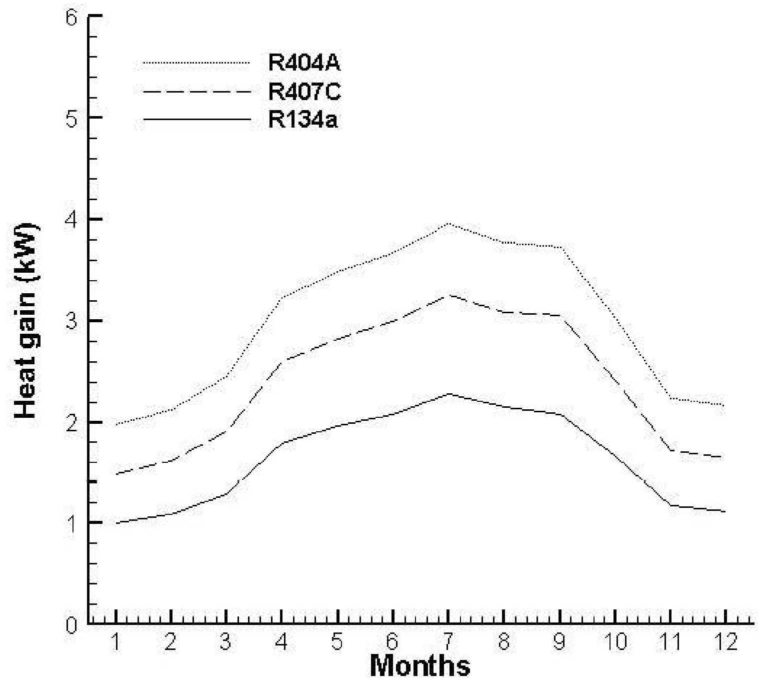


Fig. 8 – The evaporator heat gain (Almaty, Kazakhstan)

The maximum amount of heat that takes the refrigerants from the hybrid PV-T system absorber is in July month: R404A – 3.69 kW, R407C – 3.26 kW, R134a – 2.27 kW. The minimum is in January: R404A – 1.97 kW, R407C – 1. 49 kW, R134a – 1.01 kW.

CONCLUSION

Numerical modeling of photovoltaic thermal evaporator for heat pumps under meteorological conditions of Almaty city (Kazakhstan) has been conducted. Results are shown for currently available data for the total solar radiation on a horizontal surface with the actual conditions of cloudiness. Mathematical and numerical tools that include a heat balance and conservation laws to predict performance of PV-T system are created. In the future it is planned to apply this algorithm to predict the performance of the solar assisted heat pump experimental setup using PV-T evaporator with circular and triangular tube configurations [12] for the meteorological conditions of Coimbatore city in India.

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