Journal of Thermal Engineering
Web page info: https://jten.yildiz.edu.tr
DOI: 10.18186/thermal.1333904

Journal of Thermal Engineering

Research Article

Effect of operating parameters on the performance of rotary desiccant wheel energized by PV/T collectors

Umutcan OLMUŞ[1,*], Yunus Emre GÜZELEL[1], Kamil NEYFEL ÇERÇI[2], Orhan BÜYÜKALACA[1]

[1]*Department of Mechanical Engineering, Çukurova University, Adana, Türkey*
[2]*Department of Materials Engineering, Tarsus University, Mersin, Turkey*

ARTICLE INFO

Article history
Received: 01 February 2022
Revised: 04 May 2022
Accepted: 26 May 2022

Keywords:
Desiccant Air-Conditioning; Rotary Desiccant Wheel; Silica-gel; Photovoltaic Thermal Collector; Regeneration Temperature

ABSTRACT

The main energy input of a desiccant air conditioning system is the low-quality thermal energy required for regeneration, which can be obtained from waste heat, geothermal resources or solar energy. Regeneration thermal energy can be produced as well as energizing components such as fans, pumps, auxiliary air heaters, and control elements of the system by using photovoltaic-thermal solar collectors (PV/T). In this study, parametric analyzes were performed to investigate the effect of regeneration temperature and air frontal velocity on the temperature and dehumidification performance of a solid silica-gel desiccant wheel and on the water-cooled PV/T collectors used to provide the regeneration thermal energy. The regeneration temperature was varied between 50 and 70°C, and air frontal velocity between 1.3 and 4.1 m/s. The analyzes show that the dehumidification efficiency increases from 13.94% to 33.04% as regeneration temperature increased from 50°C to 70°C at 1.3 m/s air frontal velocity at which dehumidification efficiency is maximum. At 4.1 m/s air frontal velocity, the required regeneration thermal energy is maximum and increases from 49.64 kW to 132.48 kW at the same regeneration temperature change. The low regeneration temperature resulted in desirable latent performance and undesirable sensible heat transfer performance in DEW. Finally, considering the whole system, it was concluded that the optimum regeneration air temperature for the performance parameters is 60°C.

Cite this article as: Olmuş U, Güzelel YE, Neyfel Çerçi K, Büyükalaca O. Effect of operating parameters on the performance of rotary desiccant wheel energized by PV/T collectors. J Ther Eng 2023;9(4):988–997.

INTRODUCTION

Development of technology and industry and the increase in human living spaces cause an increase in the need for air-conditioning and, accordingly, an increase in energy consumption. The energy requirement for air-conditioning is one of the biggest reasons of energy consumption in buildings in modern societies [1]. The high electricity requirement puts a significant pressure on the electricity supply network [2]. Reducing the environmental damage caused by the refrigerants used in conventional systems

***Corresponding author.**
*E-mail address: uolmus@cu.edu.tr

This paper was recommended for publication in revised form by Regional Editor Tolga Taner

Published by Yıldız Technical University Press, İstanbul, Turkey

is also very important in terms of environmental protection [3]. Today, a substantial part of energy production is provided by fossil fuels, but due to the gradual decrease of resources and the damage they cause to the environment, many efforts are made to utilize alternative resources, such as solar, wind and geothermal more widely [4].

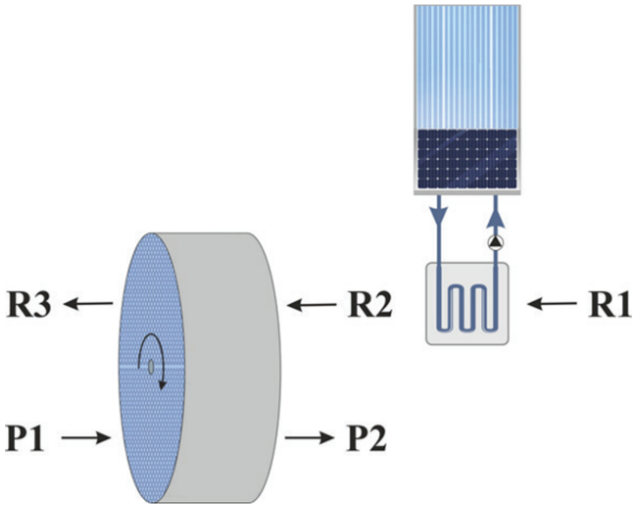

Figure 1. Schematic view of the desiccant wheel studied.

The main objective in the design of air-conditioning systems is to provide thermal comfort and reduce energy consumption [5]. Desiccant air-conditioning systems (DAC) are good alternative to the conventional ones, as they can be energized with low-quality thermal energy and do not contain environmentally harmful refrigerants [6]. Many studies have been carried out to meet the energy needs of desiccant air-conditioning systems with alternative clean energy sources such as solar and geothermal energies or waste heat [7-9]. The use of solar energy offers great potential in reducing both high-quality electricity consumption and environmental problems [10].

Solar thermal collectors are a widely-used commercial technology that converts sunlight into thermal energy. Many researchers have studied thermal cooling systems integrated with different types of solar collectors such as flat plate, vacuum tube and concentrated solar collectors [11-13]. Although the efficiency of solar thermal collectors is higher than that of solar photovoltaic (PV) panels, thermal cooling devices have a lower coefficient of performance (COP) than conventional compression cooling systems [14]. This results in larger collector areas compared to vapor compression systems driven by PV modules. In addition, the cost of thermal cooling devices can be relatively high, especially in small systems. Therefore, there is a need for alternative solutions that can increase the competitiveness of solar thermal cooling systems [15]. Photovoltaic/thermal (PV/T) collectors can provide a cost-effective solution for thermal cooling systems, because they generate both electricity and thermal energy from incoming solar radiation. In addition, removing heat from a PV/T module not only increases the electrical efficiency of the PV/T module but also extends its lifespan. The electrical energy gain from the efficiency-enhanced PV/T module may be greater than the energy consumed by parasitic components in the system, such as fans or pumps. This can result in higher total energy conversion than a stand-alone PV module or a stand-alone solar thermal collector [16].

Desiccant wheel (DEW), used to remove moisture from the process air, is a crucial component of solid desiccant air-conditioning systems [17]. A schematic view of the desiccant wheel integrated with water-cooled PV/T collector is shown in Figure 1. The wheel consists of two sections called process and regeneration. The states P1 and P2 represent the process air inlet and outlet, and states R2 and R3 shows regeneration air inlet and outlet, respectively. While the moist outdoor air passes through the process section of DEW, its humidity decreases and the temperature increases (P1→P2). On the other hand, the same outdoor air is heated to regeneration temperature with PV/T water collectors (R1→R2) in the regeneration side. The hot air that gained the ability to absorb moisture discharges the moisture out of system (R2→R3). The change of process and regeneration air streams at 1.3 m/s frontal velocity and 60 °C regeneration temperature is shown in psychometric diagram (Figure 2).

Different desiccant materials such as silica-gel, molecular sieve, zeolite, superadsorbent polymer, metal silicate are used in DEW equipment. Silica-gel is commonly used as desiccant material among these materials. In addition to desiccant material used, there are other factors that affect the performance of a DEW. These include regeneration temperature, air frontal velocity, wheel speed, area ratio of the process and regeneration sections, specifications of DEW such as diameter and thickness. Since many factors affect the performance of a DEW, the researchers focused in their studies [18, 19] on these parameters to reveal their influence. In addition, many researchers worked on renewable energy technologies, which are more environmentally friendly in terms of emission and more suitable in terms of energy consumption instead of traditional technologies, in obtaining the regeneration thermal energy [20]. Yamaguchi and Saito [21] conducted experimental and numerical analysis of DEW. The authors analyzed the effects of regeneration temperature, air velocity, wheel thickness and rotational speed on the performance of DEW. It was observed that with the increase of the regeneration temperature, the process outlet temperature also increased, and humidity decreased. Kamar et al. [22] experimentally investigated the effects of regeneration temperature on the performance of DEW. Process outlet air temperature, temperature and dehumidification efficiencies were considered as performance criteria. The results showed that increasing regeneration temperature increased process outlet temperature, decreased the thermal and dehumidification efficiencies of DEW. Saputra et al. [23] carried out an experimental investigation on the dehumidification performance of DEW at different regeneration temperatures and regeneration airflow velocities. It was seen that amount of dehumidification increased with increasing regeneration temperature and airflow velocity. Goodarzia et al. [24] evaluated the moisture removal capacity, sensible, latent and total coefficient of performance of DEW at different operating conditions using manufacturer software. They varied the regeneration temperature between 65 °C and 110 °C. Their results indicated that COP decreases and moisture removal capacity increases with increasing regeneration temperature.

Generating regeneration thermal energy using PV/T is one of the alternative applications that reduce energy consumption in desiccant based air-conditioning systems. Therefore, it is necessary to examine the effects of DEW and PV/T equipment on each other for different operating conditions.

Literature survey reveals that, studies examining the effects of regeneration temperature and air frontal velocity together in DEW systems energized by PV/T water collectors are very limited. In this study, the effect of regeneration temperature on the performance parameters of PV/T supported DEW was investigated for different air frontal velocities. Climatic conditions of Osmaniye province were taken into consideration in the analysis. Despite their potential advantages, solar DAC systems are very limited in use because of some deterrents. In the design of DEW, which is the most important component of DAC systems, knowing the effect of important parameters that affect the behavior of DEW will help to design DEW more accurately. The results obtained in this study provide helpful information for the proper design of DEW and therefore DAC systems, which may ultimately contribute to the spread of DAC systems.

MATERIAL AND METHODS

In this study, the effect of regeneration temperature on the performance of silica-gel desiccant wheel was investigated at different air frontal velocities. A machine learning algorithm model developed by [25] was used to estimate the humidity ratio (ω_{P2}) and temperature (T_{P2}) of the process air at the outlet of the DEW. Güzelel et al. [25] obtained results with different methods from the data set they produced using different equations in literature and manufacturer software. The developed models were categorized into three main groups as Multiple Linear Regression (MLR), Multilayer Perceptron Regressor (MLP_R) and Decision Tree (DT). It was reported that the predictions obtained from the MLP_R model agree well with the experimental results. Therefore, in this study, the temperature and humidity ratio at the DEW outlet were calculated using the MLP_R model with sigmoid activation function, which was reported by [25] as the best MLP_R model.

The considered DEW is divided into two symmetrical areas ($A_p = A_r$) that have an equal mass flow rate ($\dot{m}_p = \dot{m}_r$) and thus air frontal velocities are also equal ($V_p = V_r = V$). This arrangement is called balanced flow. In this study, PV/T water collectors connected in series and parallel were used to provide the thermal energy requirement of the desiccant wheel. A PV/T water collector with a total area 2 m^2 consists of 3.2 mm thickness of glass cover, 0.66 m^2 photovoltaic module, 0.2 mm-thick selective copper absorber plate, 10 copper water tubes and 50 mm insulation. The design parameters used in simulations are given in Table 1. The design parameters used in the simulations are the values for a typical water cooled PV/T collector [8, 26]. Details of the PV/T model and definitions of terms in the equations were presented in [27].

Energy balance equation for solar cell can be written as;

$$\alpha_{sc}\tau_g\beta GWdx = \eta_{sc}\tau_g\beta GWdx + U_{sc,ap}(T_{sc} - T_{ap})Wdx + U_{sc,e}(T_{sc} - T_e)Wdx \quad (1)$$

and solar cell temperature (T_{sc}) is calculated from the equation below;

$$T_{sc} = \frac{(\alpha\tau)_{1,eff} + U_{sc,e}T_e + U_{sc,ap}T_{ap}}{U_{sc,ap} + U_{sc,e}} \quad (2)$$

The absorber plate receives thermal energy from the radiation from glazing and non-packing area of the PV module. This thermal energy is transferred from absorber plate to the water tubes to heat water. Energy balance equation for absorber plate is;

$$\begin{aligned}&\alpha_{ap}(1-\beta){\tau_g}^2 GWdx + U_{sc,ap}(T_{sc} - T_{ap})Wdx \\ &= F'h_{apw}(T_{ap} - T_w)Wdx + U_{ap,e}(T_{ap} - T_e)Wdx\end{aligned} \quad (3)$$

and absorber plate temperature (T_{ap}) can be calculated from;

$$T_{ap} = \frac{\left[(\alpha\tau)_{2,eff} + PF_1(\alpha\tau)_{1,eff}\right] G + U_{L2}T_e + h_{apw}T_w}{U_{L2} + h_{apw}} \quad (4)$$

The thermal energy gain by the water is as equation (5);

$$\dot{m}_w c_w \frac{dT_w}{dx} dx = F'h_{apw}(T_{ap} - T_w)Wdx \quad (5)$$

Outlet water temperature at the end of the N^{th} PV/T collector ($T_{w,o,N}$) can be calculated from equation (6);

$$T_{w,o,N} = \frac{(AF_R(\alpha\tau))_1}{\dot{m}_w c_w}\left(\frac{1-K_k^N}{1-K_k}\right)G + \frac{(AF_R U_L)_1}{\dot{m}_w c_w}\left(\frac{1-K_k^N}{1-K_k}\right)T_e + K_k^N T_{w,i,1} \quad (6)$$

The rate of useful thermal energy gain from N identical PV/T collectors connected in series ($\dot{Q}_N$) can be calculated using the following equation;

$$\dot{Q}_N = \dot{m}_w c_w(T_{w,o,N} - T_{w,i,1}) \quad (7)$$

Temperature dependent electrical efficiency of solar cell ($\eta_{c,N}$) and PV module ($\eta_{m,N}$), and thermal efficiency of N^{th} PV/T water collector ($\eta_{th,N}$) can be calculated equations (8), (9) and (10) respectively;

$$\eta_{sc,N} = \eta_0\left[1 - \beta_0\left(\bar{T}_{sc,N} - T_0\right)\right] \tag{8}$$

$$\eta_{m,N} = \eta_{sc,N}\, \tau_g\, \beta \tag{9}$$

$$\eta_{th,N} = \frac{\dot{Q}_{th,N}}{G\, A_{PVT}} \tag{10}$$

The PV/T model utilized was validated with experimental data and good agreement between the model and experimental data was reported [27]. The mathematical model of the system was solved on EES (Engineering Equation Software) platform. DEW outlet conditions ($T_{\text{p,out}}$ and $\omega_{\text{p,out}}$) were calculated from the MLP_R model using WEKA (Waikato Environment for Knowledge Analysis) software.

Table 1. Design parameters used in the simulations [8, 26].

Parameter	Symbol	Value
Transmissivity of glass	τ_g	0.95
Thermal conductivity of glass	k_g	1 W/mK
Absorptivity of solar cell	α_{sc}	0.9
Reference solar cell efficiency	η_0	0.22
Temperature coefficient	β_0	0.0029 1/°C
Packing factor of PV module	β	0.83
Absorptivity of plate	α_{ap}	0.95
Thermal conductivity of plate	k_{ap}	384 W/mK
Water flow rate	$\dot{m}_w$	0.06 kg/s
Diameter of water tube	d	0.0127 m
Spacing between tubes	δ_t	0.1 m
Thermal conductivity of insulation	k_{ins}	0.03 W/mK
Inclination of PV/T collectors	θ	20°

In this study, the effect of regeneration temperature on outlet temperature and humidity was investigated at different air frontal velocities for Osmaniye province. Summer outdoor design dry-bulb and wet-bulb temperatures and humidity ratio for Osmaniye are 38 °C, 26 °C and 16.26 g/kg, respectively. The analyzes were carried out between 50-70 °C regeneration temperatures and at four different air frontal velocities (Table 2).

Table 2. Regeneration temperature and air frontal velocity values used in analysis

Parameter	Range
Regeneration temperature (°C)	50-70
Air frontal velocity (m/s)	1.3, 2.2, 3.1, 4.1

Performance of DEW was expressed in terms of dehumidification (η_ω) and temperature (η_T) efficiencies that can be calculated from the following equations:

$$\eta_\omega = \frac{\omega_{P1} - \omega_{P2}}{\omega_{P1}} \tag{11}$$

$$\eta_T = \frac{T_{P2} - T_{P1}}{T_{R2} - T_{P1}} \tag{12}$$

RESULTS AND DISCUSSION

In recent years, many researchers have been working on increasing the performance of the solid desiccant wheels in air-conditioning systems and providing the regeneration energy required to remove moisture with renewable energy technologies. In this study, parametric analyzes were performed on the effects of regeneration temperature (T_{reg}) and air frontal velocity (V) on the performance of the solid desiccant wheel and the effects of these variables on the PV/T system used to provide the regeneration thermal energy. Osmaniye cooling design conditions were taken into consideration in the parametric analysis. Variation of the temperature and humidity for the process and regeneration air streams are shown on the psychometric diagram for the determined input parameters in Figure 2. The psychometric diagram shows that approximately 4 g/kg of moisture is removed from the process air at regeneration temperature of 60 °C and air frontal velocity of 1.3 m/s. At the same time, the temperature of the process air increases by approximately 13 °C during dehumidification.

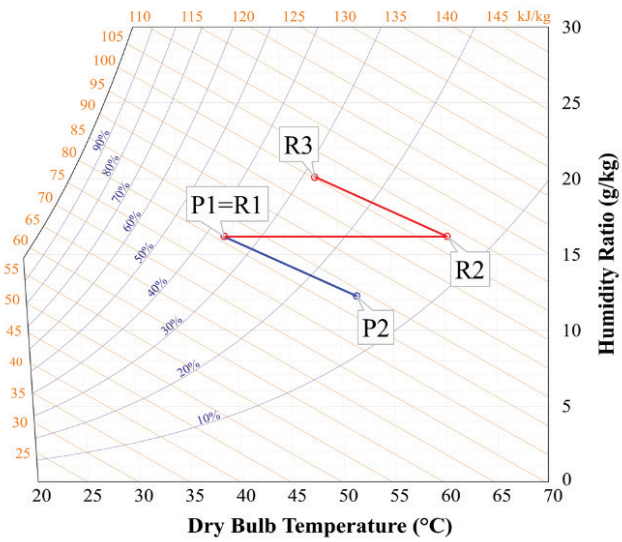

Figure 2. Psychrometric diagram for 60 °C regeneration temperature and 1.3 m/s air frontal velocity.

In Figure 3, the variation of the humidity (**a**) and temperature (**b**) differences on the process side of the DEW with regeneration temperature are presented for four different frontal velocities. It is observed from the figure that both the humidity and temperature differences increase with the increase of the regeneration temperature. $\Delta\omega_{pro}$ and ΔT_{pro} increases respectively from 2.27 g/kg and 7.36 °C to 5.37 g/kg and 18.73 °C when regeneration temperature is increased from 50 °C to 70 °C at V=1.3 m/s. This corresponds 137.04% and 154.45% increase in $\Delta\omega_{pro}$ and ΔT_{pro}, respectively. One of the most important parameters triggering dehumidification of the process air in DEW is the regeneration temperature, and the amount of dehumidification increased with the increase in the regeneration temperature.

Considering the effect of air frontal velocity, the humidity and temperature differences decrease with the increase of air frontal velocity at a given regeneration temperature, in contrast to the trend seen at the regeneration temperature. Because the larger volume flow causes the desiccant bed to come into contact with more humid air and leads to faster saturation. In addition, the effect of air frontal velocity on humidity and temperature differences is more at high regeneration temperatures than at low regeneration temperatures. $\Delta\omega_{pro}$ and ΔT_{pro} decreases respectively from 5.37 g/kg and 18.73 °C to 4.13 g/kg and 12.24 °C when velocity is increased from 1.3 m/s to 4.1 m/s at 70 °C regeneration temperature. This corresponds 30.08% and 52.97% decrease in $\Delta\omega_{pro}$ and ΔT_{pro}, respectively. The observed trends in the moisture removed from the process air with air frontal velocity and regeneration temperature are consistent with trends reported in the literature [15, 28, 29].

Considering the variations in dehumidification and temperature efficiencies with regeneration temperature, it is determined that these parameters exhibit opposite trends (Figure 4). The effect of frontal velocity on both efficiencies is the same; when velocity increases both

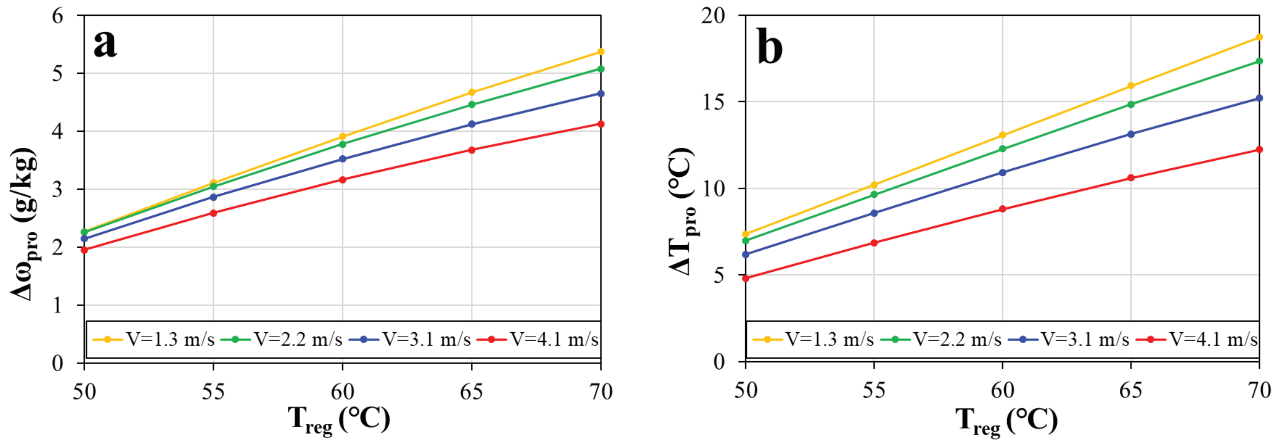

Figure 3. Variation of moisture removed (**a**) and temperature increase (**b**) in desiccant wheel with regeneration temperature.

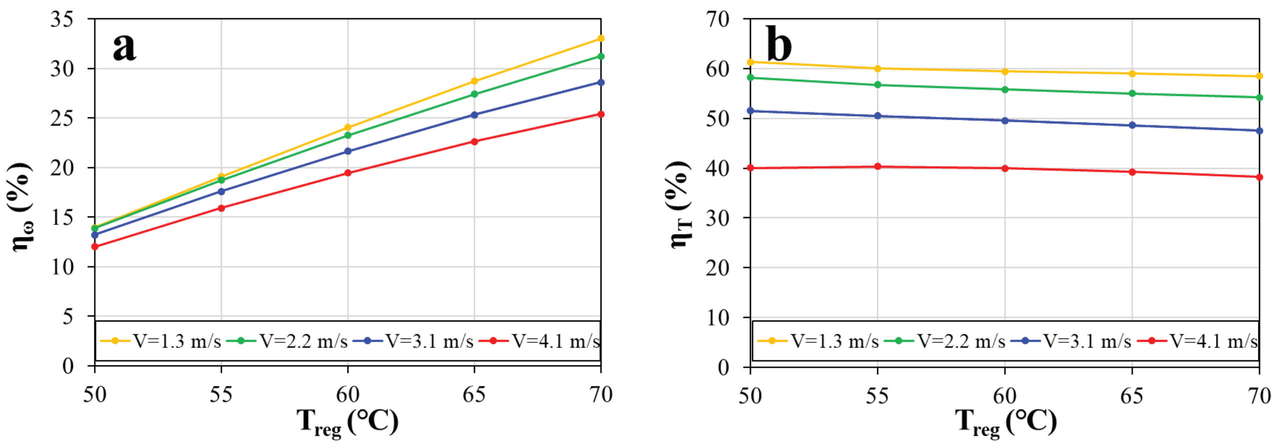

Figure 4. Dehumidification (**a**) and temperature effectiveness (**b**) of desiccant wheel.

efficiencies decrease. η_ω is directly related to the humidity difference in the process air and is therefore more affected by the change of air frontal velocity with the increase in regeneration temperature, similar to the results obtained in Figure 3-a.

Compared to higher regeneration temperatures, at low regeneration temperatures (especially at 50 °C) η_ω values are close to each other for all velocities tested. η_ω increases from 13.94% to 33.04% and, η_T decreases from 61.33% to 58.52%, when regeneration temperature is increased from 50 °C to 70 °C at V=1.3 m/s, respectively.

Variation of the thermal energy required to regenerate DEW ($\dot{Q}_{reg}$) with regeneration temperature is presented in Figure 5 for different frontal velocities. Increase in regeneration temperature and air frontal velocity results in higher $\dot{Q}_{reg}$. The change in air frontal velocity means a change in the amount of air passing through the DEW. Therefore, as V increases, the thermal energy requirement also increases. $\dot{Q}_{reg}$ increases from 40.74 kW to 132.48 kW (approximately 225% increase) when velocity is increased from 1.3 m/s to 4.1 m/s at 70 °C. In addition, $\dot{Q}_{reg}$ increases from 49.64 kW to 132.48 kW (approximately 167% increase) when regeneration temperature is increased from 50 °C to 70 °C at 4.1 m/s.

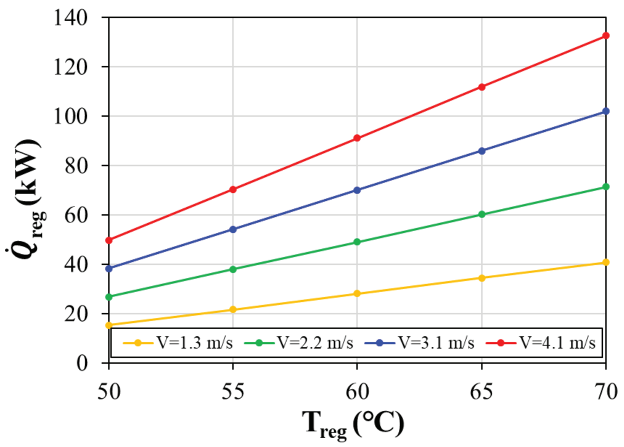

Figure 5. Effect of regeneration temperature on required regeneration thermal energy

The moisture removed from the process air per unit regeneration thermal energy expended ($\Delta\omega_{pro}/\dot{Q}_{reg}$) is an important parameter to measure the performance of DEW. In Figure 6 (a), the variation of ($\Delta\omega_{pro}/\dot{Q}_{reg}$) with regeneration temperature is given for different air frontal velocities. Increasing regeneration temperature and air frontal velocity negatively affects the parameter ($\Delta\omega_{pro}/\dot{Q}_{reg}$). However, it should be noted the parameter ($\Delta\omega_{pro}/\dot{Q}_{reg}$) is strongly affected by air frontal velocity at a fixed regeneration temperature. For instance, ($\Delta\omega_{pro}/\dot{Q}_{reg}$) decreases from 0.13 (g/kg)/kJ to 0.03 (g/kg)/kJ when velocity is increased from 1.3 m/s to 4.1 m/s at 70 °C. This can be explained by the decrease in dehumidification effectiveness (Figure 4) with increasing frontal velocity.

During dehumidification process, temperature of process air also increases. This is not desirable as it increases the capacity and energy consumption of the cooling system used downstream of DEW. Therefore, the parameter ($\Delta T_{pro}/\dot{Q}_{reg}$) should be kept low in desiccant cooling applications. The parameter ($\Delta T_{pro}/\dot{Q}_{reg}$) is slightly affected by the variation of regeneration temperature, as expected (Figure 6 (b)). However, for a unit regeneration thermal power expended, the temperature increase of process air decreases considerably with increasing air frontal velocity and thus air flow rate. It can be concluded from Figure 6 that low regeneration temperature is desirable for the latent performance ($\Delta\omega_{pro}/\dot{Q}_{reg}$) and unfavorable for the sensible heat transfer performance ($\Delta T_{pro}/\dot{Q}_{reg}$) of DEW. However, if the dehumidification rate is the primary design consideration only, dehumidification effectiveness (η_ω) is the key design parameter. In this case, regeneration temperature should be high.

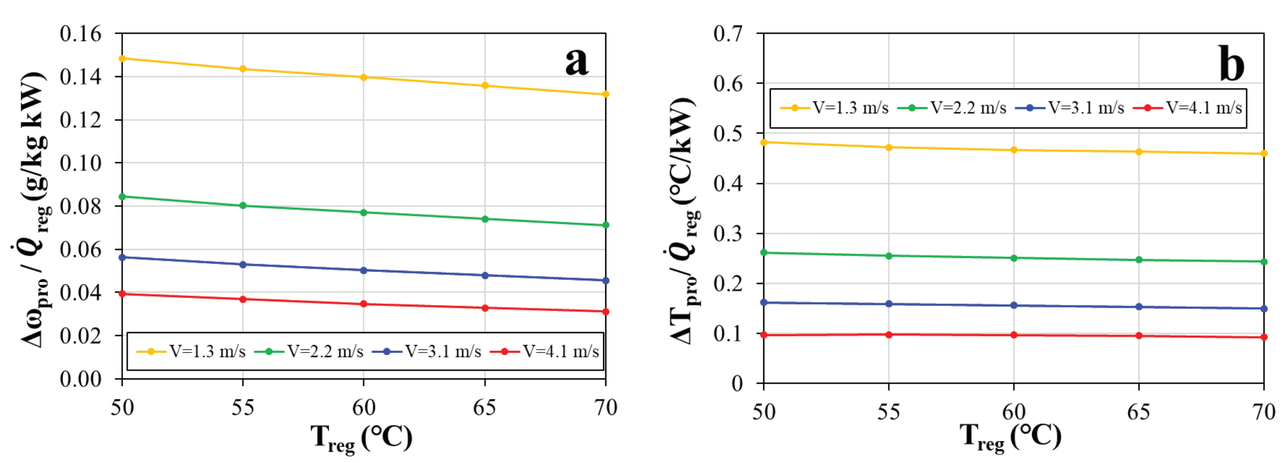

Figure 6. Variation of ($\Delta\omega_{pro}/\dot{Q}_{reg}$) **(a)** and ($\Delta T_{pro}/\dot{Q}_{reg}$) **(b)** with regeneration temperature

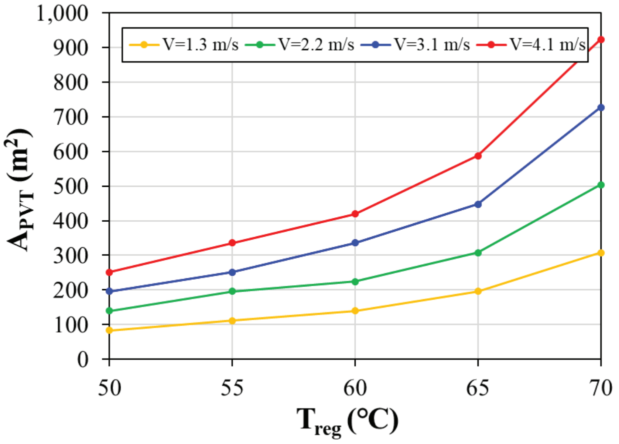

Figure 7. Effect of regeneration temperature on required PV/T collector area.

Figure 7 presents the variation of the PV/T water collector area needed ($A_{PV/T}$) to generate regeneration thermal energy with regeneration temperature for different frontal velocities. $A_{PV/T}$ increases with increasing regeneration temperature and air frontal velocity, similar to the $\dot{Q}_{reg}$ (Figure 5). It is an expected result as more PV/T collectors are needed as regeneration thermal energy increases. However, while the increase in the $\dot{Q}_{reg}$ exhibits a linear variation with regeneration temperature, the increase in $A_{PV/T}$ surface area shows a polynomial increasing trend. At higher regeneration temperatures, the required PV/T collector area increases faster with increasing air velocity than at lower regeneration temperatures.

Thermal efficiency of PV/T water collector (η_{th}) and electrical efficiencies of the cell (η_{sc}) and module (η_m) are presented in Figure 8, respectively. It can be seen from the figure that with the increase of the regeneration temperature, no change is observed in all three efficiencies until 60 °C regeneration temperature. In this region, η_{th}, η_{sc} and η_m are 50.78%, 19.90% and 17.02%, respectively. After this critical temperature, all three efficiencies decrease due to increase in thermal losses from the collector. Thermal efficiency decreases from 50.78% to 33.42% when regeneration temperature is increased from 60 °C to 70 °C. Cell and module efficiencies decrease respectively from 19.90% to 19.58% and from 17.02% to 16.74% when regeneration temperature is increased from 60 °C to 70 °C. In general, both efficiencies obtained in the analyzes are consistent with the results reported in the literature [8, 30, 31].

Variation of $\Delta\omega/A_{PV/T}$ and $A_{PV/T}/\dot{Q}_{reg}$, which are two important parameters in determining the suitable working conditions of PV/T supported solid desiccant wheels, are illustrated in Figure 9. The regeneration temperature that removed the most moisture ($\Delta\omega$) per PV/T area ($A_{PV/T}$), is found to be 60 °C for the low air frontal velocities (1.3 and 2.2 m/s). However, the most suitable regeneration temperature is 55 °C for 3.1 m/s. The best results for $\Delta\omega/A_{PV/T}$ are obtained at air frontal velocity of 1.3 m/s. It is observed that while $\Delta\omega/A_{PV/T}$ increases 3.52% when regeneration temperature is increased from 50 °C to 60 °C, $\Delta\omega/A_{PV/T}$ decreases 37.55% when it is increased from 60 °C to 70 °C at 1.3 m/s. In addition, the most appropriate regeneration temperature value in terms of required the least PV/T area ($A_{PV/T}$) per heating load ($\dot{Q}_{reg}$) is found to be 60 °C for all air frontal velocities conditions. Although $A_{PV/T}/\dot{Q}_{reg}$ decreases respectively from 5.50 m^2/kW to 5.00 m^2/kW when regeneration temperature is increased from 50 °C to 60 °C, it increases respectively from 5.00 m^2/kW to 7.56 m^2/kW when regeneration temperature is increased from 60 °C to 70 °C at V=1.3 m/s. When PV/T water collector investment is considered, it is seen that the optimum regeneration temperature is 60 °C for all conditions covered in this study.

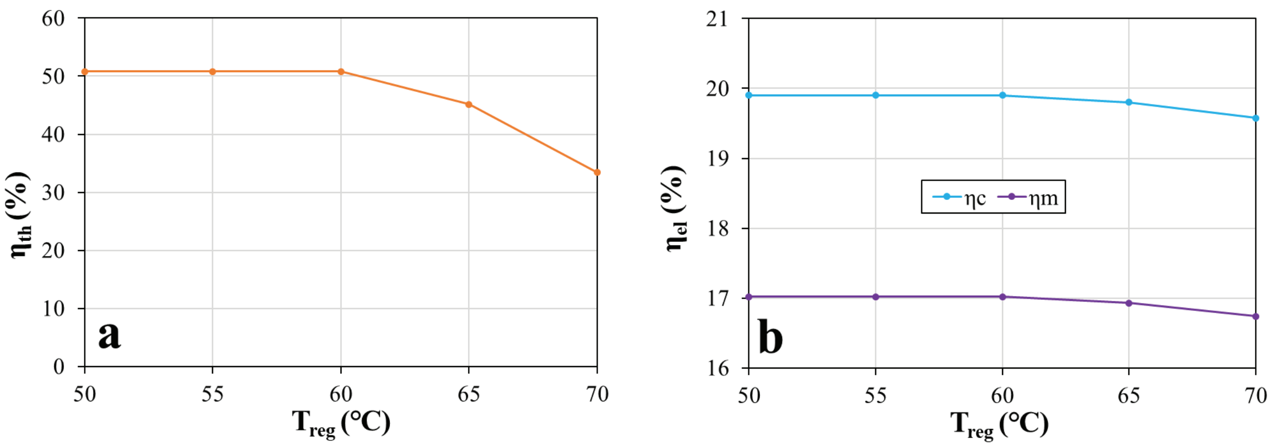

Figure 8. Variation of thermal **(a)**, solar cell and module efficiency **(b)** with regeneration temperature.

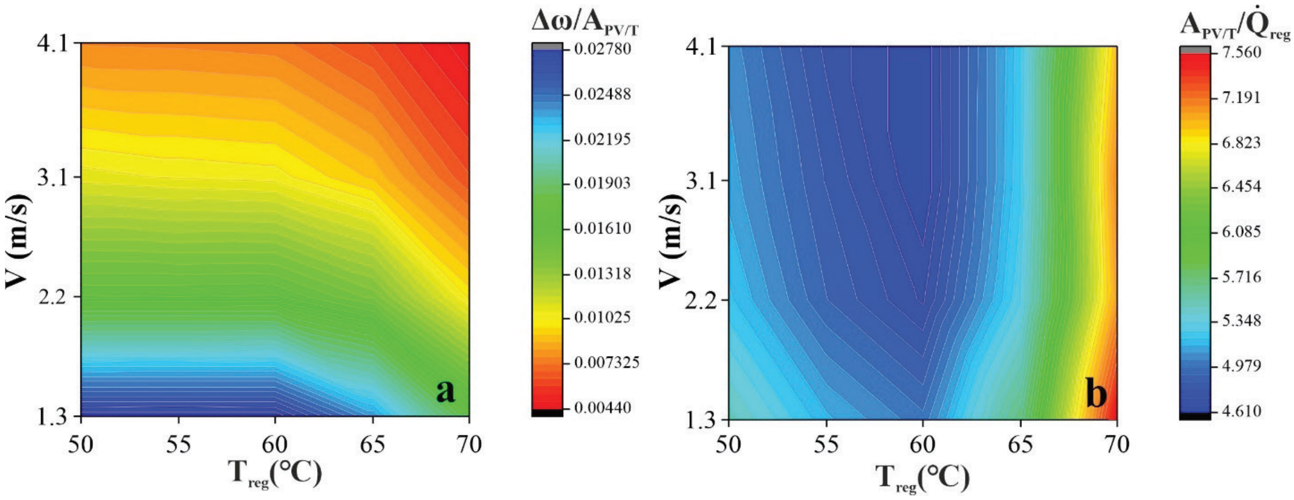

Figure 9. Variation of moisture removed per PV/T area **(a)** and required PV/T area per regeneration thermal energy **(b)** with regeneration temperature and air frontal velocity.

CONCLUSION

Operating parameters are of great importance in renewable energy supported air- conditioning systems where drying wheels are used. The use of PV/T water collectors in generating regeneration thermal energy for solid desiccant wheels, especially in humid and rural areas, has been the focus of attention of many researchers. In this study, a parametric study was conducted to investigate the variation of the performance parameters of the PV/T supported solid desiccant wheel with regeneration temperature for different air frontal velocities. The results obtained in the study are as follows;

With the increase of the regeneration temperature, the dehumidification capacity ($\Delta\omega_{pro}$) and dehumidification effectiveness (η_{ω}) of DEW and the regeneration thermal energy ($\dot{Q}_{reg}$) required to heat the regeneration increased air for all velocities tested. η_{ω} increases by 19.10% and, η_T decreases by 2.81%, when regeneration temperature increases from 50 °C to 70 °C for minimum air frontal velocity value.

Since $\dot{Q}_{reg}$ increases more than $\Delta\omega_{pro}$ and ΔT_{pro} with the increasing regeneration temperature, low regeneration temperature is desirable for the latent performance ($\Delta\omega_{pro}/\dot{Q}_{reg}$) and undesirable for the sensible heat transfer performance ($\Delta T_{pro}/\dot{Q}_{reg}$) of DEW.

The PV/T area needed per regeneration thermal energy ($A_{PVT}/\dot{Q}_{reg}$) decreases slightly up to 60 °C and then increases with increasing regeneration temperature for all velocities. When the whole system (desiccant wheel and PV/T water collectors) is considered, the optimal regeneration air temperature for the performance parameters ($\Delta\omega_{pro}/A_{PV/T}$ and $A_{PV/T}/\dot{Q}_{reg}$) is 60 °C. Thermal efficiency decreases by 17.36% when regeneration temperature is increased from 60 °C to 70 °C. Cell and module efficiencies decrease respectively by 0.32% and 0.28% respectively, when regeneration temperature is increased from 60 °C to 70 °C.

Choosing the appropriate operating parameters contributes to the more energy efficient operation of desiccant air-conditioning systems and ultimately to the spread of such systems. In this preliminary study, the effects of regeneration temperature and air frontal velocity on the performance parameters of PV/T supported desiccant wheels were investigated under a certain climatic condition. More studies are needed for different climatic conditions to reveal the effect of these parameters in a more detail manner.

NOMENCLATURE

c	specific heat (J/kgK)
G	solar radiation (W/m^2)
N	number of PV/T collectors connected in series
$\dot{Q}$	rate of heat transfer (kW)
T	temperature (°C) or (K)
U	overall heat transfer coefficient (W/m^2 K)
V	air frontal velocity (m/s)
η_{sc}	electric efficiency of solar cell
η_m	electric efficiency of PV module
η_{th}	thermal efficiency of PV/T collector

Subscripts

ap	absorber plate
e	ambient
sc	solar cell
m	module
o	outlet
pro	process air
reg	regeneration air
w	water

Abbreviations

DAC desiccant air-conditioning
DEW desiccant wheel
PV/T photovoltaic-thermal collector

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

REFERENCES

[1] Guo J, Bilbao JI, Sproul AB. A novel solar cooling cycle - A ground coupled PV/T desiccant cooling (GPVTDC) system with low heat source temperatures. Renewable Energy 2020;162:1273−1284. [CrossRef]
[2] Fan H, MacGill IF, Sproul AB. Statistical analysis of driving factors of residential energy demand in the greater Sydney region, Australia. Energy Build 2015;105:9−25. [CrossRef]
[3] Rahman S, Said Z, Issa S. Performance evaluation and life cycle analysis of new solar thermal absorption air conditioning system. Energy Rep 2020;6:673−679. [CrossRef]
[4] Temiz M, Dincer I. A unique bifacial PV and hydrogen-based cleaner energy system with heat recovery for data centers. Appl Therm Eng 2022;206:118102. [CrossRef]
[5] Kassas M, Hamanah WM, Al-Tamimi O, Sahin A, Yilbas BS, Ahmed CB. Operation of HVAC system for energy savings and economic analysis. J Therm Eng 2019;5:181−197. [CrossRef]
[6] Uçkan İ, Yılmaz T, Büyükalaca O. Effect of operation conditions on the second law analysis of a desiccant cooling system. Appl Therm Eng 2017;113:1256−1265. [CrossRef]
[7] Heidarinejad G, Rayegan S, Pasdarshahri H. Dynamic simulation of a solar desiccant cooling system combined with a ground source heat exchanger in humid climates. J Build Eng 2020;28:101048. [CrossRef]
[8] Olmuş U, Güzelel YE, Pınar E, Özbek A, Büyükalaca O. Performance assessment of a desiccant air-conditioning system combined with dew-point indirect evaporative cooler and PV/T. Sol Energy 2022;231:566−577. [CrossRef]
[9] Speerforck A, Ling J, Aute V, Radermacher R, Schmitz G. Modeling and simulation of a desiccant assisted solar and geothermal air conditioning system. Energy 2017;141:2321−2336. [CrossRef]
[10] Shahsavari A, Akbari M. Potential of solar energy in developing countries for reducing energy-related emissions. Renew Sustain Energy Rev 2018;90:275−291. [CrossRef]
[11] Kashif A, Ali M, Sheikh NA, Vukovic V, Shehryar M. Experimental analysis of a solar assisted desiccant-based space heating and humidification system for cold and dry climates. Appl Therm Eng 2020;175:115371. [CrossRef]
[12] Ma Z, Ren H, Lin W. A review of heating, ventilation and air conditioning technologies and innovations used in solar-powered net zero energy Solar Decathlon houses. J Clean Prod 2019;240:118158. [CrossRef]
[13] Roy R, Kundu B. Optimum design analysis of a solar-assisted Libr/H_2O absorption system with a flat-plate collector. J Therm Eng 2021;7:1056−1066. [CrossRef]
[14] Fong KF, Chow TT, Lee CK, Lin Z, Chan LS. Comparative study of different solar cooling systems for buildings in subtropical city. Sol Energy 2010;84:227−244. [CrossRef]
[15] Eicker U, Schneider D, Schumacher J, Ge T, Dai Y. Operational experiences with solar air collector driven desiccant cooling systems. Appl Energy 2010;87:3735−3747. [CrossRef]
[16] Hamzat AK, Sahin AZ, Omisanya MI, Alhems LM. Advances in PV and PVT cooling technologies: A review. Sustain Energy Technol Assess 2021;47:101360. [CrossRef]
[17] Çerçi KN, Hürdoğan E. Comparative study of multiple linear regression (MLR) and artificial neural network (ANN) techniques to model a solid desiccant wheel. Int Commun Heat Mass Transf 2020;116:104713. [CrossRef]
[18] Motaghian S, Rayegan S, Pasdarshahri H, Ahmadi P, Rosen MA. Comprehensive performance assessment of a solid desiccant wheel using an artificial neural network approach. Int J Heat Mass Transf 2021;165:120657. [CrossRef]
[19] White SD, Goldsworthy M, Reece R, Spillmann T, Gorur A, Lee DY. Characterization of desiccant wheels with alternative materials at low regeneration temperatures. Int J Refrig 2011;34:1786−1791. [CrossRef]
[20] Guo J, Lin S, Bilbao JI, White SD, Sproul AB. A review of photovoltaic thermal (PV/T) heat utilisation with low temperature desiccant cooling and dehumidification. Renew Sustain Energy Rev 2017;67:1−14. [CrossRef]

[21] Yamaguchi S, Saito K. Numerical and experimental performance analysis of rotary desiccant wheels. Int J Heat Mass Transf 2013;60:51−60. [CrossRef]
[22] Kamar HM, Kamsah N, Alhamid MI, Sumeru K. Effect of regenaration air temperature on desiccant wheel performance. Int J Technol 2016;2:281−287. [CrossRef]
[23] Saputra DA, Osaka Y, Tsujiguchi T, Haruki M, Kumita M, Kodama A. Experimental investigation of desiccant wheel dehumidification control method for changes in regeneration heat input. Energy 2020;205:118109. [CrossRef]
[24] Goodarzia G, Thirukonda N, Heidari S, Akbarzadeh A, Date A. Performance evaluation of solid desiccant wheel regenerated by waste heat or renewable energy. Energy Proced 2017;110:434−439. [CrossRef]
[25] Güzelel YE, Olmuş U, Çerçi KN, Büyükalaca O. Comprehensive modelling of rotary desiccant wheel with different multiple regression and machine learning methods for balanced flow. Appl Therm Eng 2021;199:117544. [CrossRef]
[26] Dubey S, Tiwari GN. Analysis of PV/T flat plate water collectors connected in series. Sol Energy 2009;83:1485−1498. [CrossRef]
[27] Shyam, Tiwari GN, Fischer O, Mishra RK, Al-Helal IM. Performance evaluation of N-photovoltaic thermal (PVT) water collectors partially covered by photovoltaic module connected in series: An experimental study. Sol Energy 2016;134:302−313. [CrossRef]
[28] Ge TS, Ziegler F, Wang RZ. A mathematical model for predicting the performance of a compound desiccant wheel (A model of compound desiccant wheel). Appl Therm Eng 2010;30:1005−1015. [CrossRef]
[29] Intini M, Goldsworthy M, White S, Joppolo CM. Experimental analysis and numerical modelling of an AQSOA zeolite desiccant wheel. Appl Therm Eng 2015;80:20−30. [CrossRef]
[30] Yu Y, Yang H, Peng J, Long E. Performance comparisons of two flat-plate photovoltaic thermal collectors with different channel configurations. Energy 2019;175:300−308. [CrossRef]
[31] Fudholi A, Sopian K, Yazdi MH, Ruslan MH, Ibrahim A, Kazem HA. Performance analysis of photovoltaic thermal (PVT) water collectors. Energy Convers Manag 2014;78:641−651. [CrossRef]