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Performance Improvement Of Solar-Assisted Desiccant Cooling System By Changing Collector Type And Stage Number

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***Abstract* –** Solar energy systems have been recognized as a significant component of HVAC systems during the last two decades, providing thermal and electrical energy for a variety of applications. Meanwhile, solar-assisted cooling systems present a great opportunity to provide thermal comfort conditions in hot and humid climate weather. In this research, a solar-assisted desiccant cooling system is presented and its performance in the hot and humid climate of Jakarta, Indonesia is evaluated using the TRNSYS 18 software. To improve and optimize the efficiency of the system, the number of stages in the cycle is changed from one to three. Furthermore, as the novelty of the research, the effect of different types of solar collectors including Direct Absorption Solar Collector (DASC), Photovoltaic Thermal (PVT), and evacuated tube collector is investigated and the COP of the system is compared. According to the results, the suggested system with two sets of desiccant and heat wheels has a greater COP. Additionally, the system with one stage has a higher COP than the system with three stages. Furthermore, using PVT solar collectors is suggested for these systems as they can provide both thermal and electrical energy for the system. PVT collector increases the system's COP to 1.3, while the evacuated tube and direct absorption solar collectors lower it to 1.215 and 1.199, respectively.

***Keywords*: Solar energy, Desiccant cooling, Photovoltaic Thermal collector, TRNSYS software**

1 Introduction

Providing thermal comfort conditions for a growing global population and addressing the environmental issues associated with current cooling technologies need the development of innovative systems with high efficiency and low emissions. Meanwhile, solar-assisted cooling systems, which may be classed as solar thermal systems, solar electrical systems, and solar mechanical systems, are regarded as the most promising technology in this field. The solar thermal cooling system which is the main topic of the current study is based on two significant phenomena of absorption and adsorption. One of the oldest cooling methods still in use today is the absorption system. Sokhansefat et al. [1] used the TRNSYS software to simulate a 5-ton solar absorption cooling system in Tehran's environment and compared the results to an existing system. They reported that the optimum values for the evacuated solar collector, storage tank volume, temperature set point of the auxiliary boiler, solar collector mass flow rate, and collector slope, in order to achieve the highest efficiency, are 55 m^2, 1 m^2, 77 °C, 1000 kg/h, and 33 degrees, respectively.

Ahmad et al. [2] demonstrated a unique method for chilling ambient air under harsh weather conditions. They proposed a cascade of absorption and mechanical chillers for input air cooling, as well as concentrated solar collectors, and evaluated the system's performance using an engineering equation solver (EES). The suggested system displayed a relative gain in power of 22.8%, an improvement in efficiency of 4.3%, and a relative decrease in specific fuel consumption of 8.2% when compared to the present power plant. Macía et al. [3] studied the effect of generator and condenser temperature on the performance of a solar-assisted absorption ground-coupled heat pump (GCHP). They utilized TRNSYS software to simulate the proposed system and an experimental system housed in a tertiary-use building in Valladolid (Spain) to validate the simulation. However, the results show that the optimal operating temperature for the heat pump's generator in terms of its best COP is not the greatest working temperature in terms of the installation's overall Global Efficiency. This tackles the issue of lengthier downtimes when the generator is required to run at greater temperatures in the solar field. Modi et al. [4] created a numerical model for the energy and exergy analysis of a single-effect lithium bromide absorption refrigeration system. They discovered that raising the temperature of the generator from 75 to 110 °C raises COP and rational efficiency.

With a generator temperature of 87 °C, the best values for COP and rational efficiency are 0.74 and 27%, respectively. When the temperature of the absorber and condenser is reduced from 45 to 30 °C, the COP rises from 0.6 to 0.78. In terms of exergy, the generator (40%) and absorber (28%), as a result of the mixing process occurring at a higher temperature, suffer the most damage; as a result, these two components require further design modifications.

Askalany et al. [5] reviewed the performance of adsorption systems with different working pairs in terms of coefficient of performance (COP), driving temperature, evaporation temperature, and specific cooling power (SCP). They classified the adsorption working pairs into different groups including physical, chemical, and composite adsorbents. According to their findings, silica gel and chloride composites/water pair have the greatest COP for the adsorption refrigeration system (0.83), whereas zeolite with water pair has the lowest COP value. The evaporation temperature for metal hydrides/hydrogen is as low as -50 °C. The driving temperatures for silica gel and chloride composites/methanol and zeolite/water are the lowest and highest, respectively. Wang [6] demonstrated that by including heat and mass recovery into an adsorption cooling system, the system's COP may be increased by 25% and 10%, respectively. The author investigated various cycles for heat and mass recovery, such as the fundamental intermittent adsorption cycle, the continuous two-adsorber heat recovery cycle, the mass recovery cycle, the mass recovery with sensible heat recovery, and the mass recovery with both sensible heat and heat of adsorption recovery. TRNSYS was utilized by Vasta et al. [7] to model a modest solar-assisted adsorption system in Milan, Rome, and Messina in Italy. They found that the system's performance is significantly dependent on heat rejection technology. They observed that a good financial assistance program can reduce the payback period for these systems to 10 years. Reda et al. [8] built and improved a solar-powered adsorption cooling system for residential usage in upper Egypt, as well as examined the system's environmental and economic effects. They employed TRNSYS software to assess the influence of the solar collector area and the hot and cold water tank capacities on the system's performance. Based on their results, the most economically viable choices are a 24 m^2 solar collecting area, a 0.6 m^3 hot storage tank, and a 1 m^3 cold storage tank. Moreover, the system's initial cost ranges from 2,897 €/kW to 4,808 €/kW, which is relatively expensive for residential and small-scale applications. The completely solar-assisted adsorption system emits 193 kg of CO_2eq./kW per year, whereas a natural gas-powered chiller emits 1062 kg of CO_2eq./kW per year.

Henning et al. [9] studied different aspects of solar-assisted desiccant cooling systems and found out that the single-stage desiccant cooling system has lower COP to provide thermal comfort conditions for residential applications. Ge et al. [10] created a test setup to evaluate the performance of a two-stage rotary desiccant cooling system under three distinct climatic conditions. They observed that the system's necessary regeneration temperature and COP are, respectively, low and high. A system with two stages requires a lower temperature for regeneration than a system with one step. Dezfouli et al. [11] tested the effectiveness of three distinct cycles for the solar-assisted desiccant cooling system and fan coil unit in Malaysia's hot and humid climate. According to their findings, the fan coil unit is incapable of providing thermal comfort, but the two-stage solar desiccant cooling system conserved 27.9% and 33.9% of energy while reducing the room temperature and relative humidity to 25.5 °C and 61-66%, respectively. Baniyounes et al. [12] recommended employing the solar desiccant cooling system to provide thermal comfort conditions in a variety of functional areas of institutional buildings. If 20 m^2 of evacuated tube collector area and 1.5 m^3 of solar hot water storage volume are utilized as opposed to 10 m^2 of solar collector area and 0.4 m^3 of the hot water tank, the system's COP and solar percentage may be increased from 0.7% to 1.2% and from 22% to 69%, respectively.

Due to its capacity to manage both humidity and temperature, solar desiccant cooling systems can be used to offer thermal comfort conditions in hot and humid climates. In the current study, a solar desiccant cooling system is presented and its performance is simulated with TRNSYS software in Jakarta in Indonesia which has a hot and humid climate condition. To improve and optimize the efficiency of the system, the number of stages in the cycle is changed from one to three. Furthermore, as the novelty of the research, the effect of different types of solar collectors including Direct Absorption Solar Collector (DASC), Photovoltaic Thermal (PVT), and evacuated tube collector is investigated and the COP of the system is compared.

2 Methodology

2.1 Problem Description

The primary objective of this study is to provide thermal comfort conditions for a typical residence in Jakarta, Indonesia (6.2088° S, 106.8456° E), which has hot and humid summers. During the hottest month of the year for Jakarta, October, the depicted system is simulated with TRNSYS.18 software. The average ambient temperature and solar radiation for different months are illustrated in Figure 1.

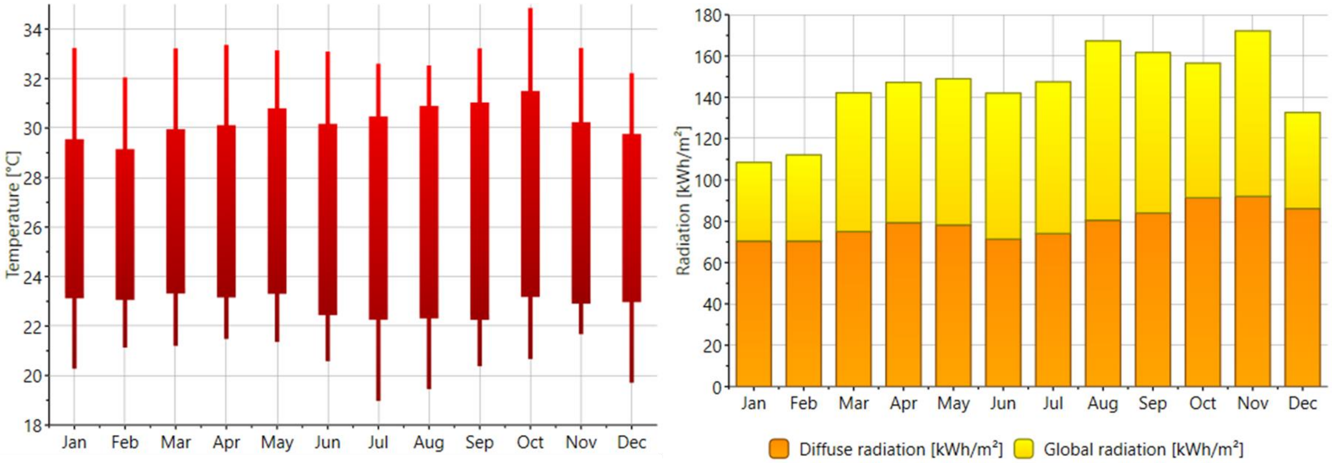

Figure 1- Average ambient temperature and solar radiation for different months in Jakarta

2.2 System Description

The temperature and humidity of the air must be regulated in order to attain thermal comfort conditions. The several components of the solar desiccant cooling system allow us to reduce humidity and then regulate the temperature of ventilation air. Figure 2 presents the components and design of the two-stage solar desiccant cooling system. Figure 2 depicts that the input stream passes through two sets of desiccant and heat wheels. After each desiccant wheel, the ventilation stream's absolute humidity and temperature are decreased and raised, accordingly. In addition, by employing the heat wheel after the desiccant wheel, the incoming stream's humidity remains constant as its temperature lowers. The low humidity of the incoming stream after desiccant and heat wheels enables us to utilize the direct evaporative cooler to decrease the temperature before entering the house. Also, the solar collector provides thermal energy for the regeneration stream, and an auxiliary heater is utilized to boost the temperature of the regeneration stream before the desiccant wheels.

In this research, the performance of the system is investigated with one to three sets of desiccants and heat wheels (one to three stages) and different types of solar collectors including Absorption Solar Collector (DASC), Photovoltaic Thermal (PVT), and evacuated tube collector.

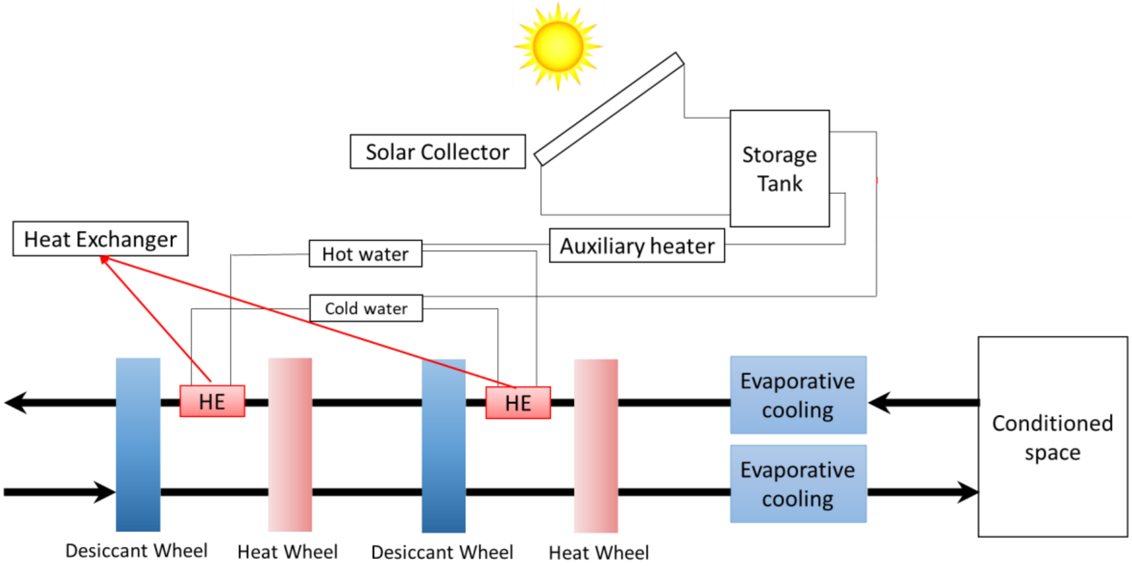

Figure 2- Schematic of two stages of solar desiccant cooling system

2.3 Governing Equations

To analyze and compare the performance of the systems under various situations, the COP is determined by Eq (1).

$$COP = \frac{Cooling\ Capacity}{P_{in} - P_{collector}} \tag{1}$$

$P_{collector}$ is the output electrical power supplied by the PVT solar collector, which may be utilized in all phases of the cycle. The cooling capacity and P_{in} can be calculated using Eqs. (2) and (3).

$$cooling\ capacity = \dot{m}_{process}(h_{amb} - h_{conditioned}) \tag{2}$$

$$P_{in} = \sum P_{fans} + \sum P_{pumps} \tag{3}$$

3 Results and Discussion

As it is mentioned in the last parts, the proposed system is simulated with three types of solar collectors and three stages of desiccant and heat wheel. The information about the main parameters which are utilized in TRNSYS 18 software is presented below:

- Desiccant wheel
- Heat wheel
- Pump
- Fan
- Storage tank (volume: 0.35 m^3)
- Evaporative cooler; (direct type)
- Working fluids: water, air
- The auxiliary heater type is electrical.

3.1 Impact of the Number of Stages

The stage number indicates the number of desiccant and heat wheel sets in the cycle. The schematics of the systems are illustrated in figure 3. It is worth mentioning that the solar collector type in this part is PVT.

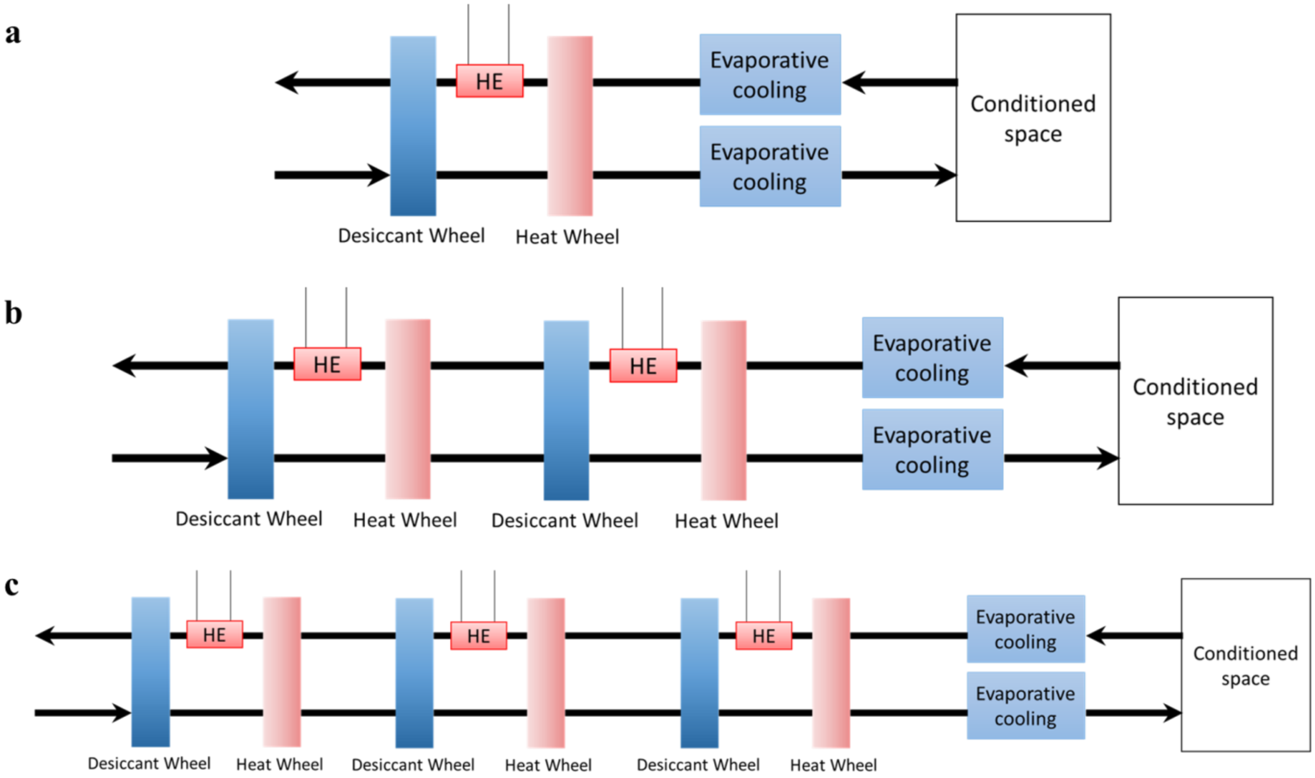

Figure 3- The schematic of the desiccant cooling system with a) one stage; b) two stages; c) three stages.

Simulation findings which are illustrated in Figure 4 indicate that by increasing the number of stages in the cycle from one to two, the system's COP increases from 0.974 to 1.3. As the number of stages increases from two to three, the COP decreases to 0.745. Therefore, it can be determined that the optimal number of stages for the system is two. This means that the process air stream cannot have its relative humidity lowered in a single pair of desiccant and heat wheels. Even if the humidity of the inlet stream is lowered after the third pair of desiccant and heat wheels in a three-stage cycle, the required thermal energy for the regeneration stream will be higher, resulting in a lower COP for the entire system.

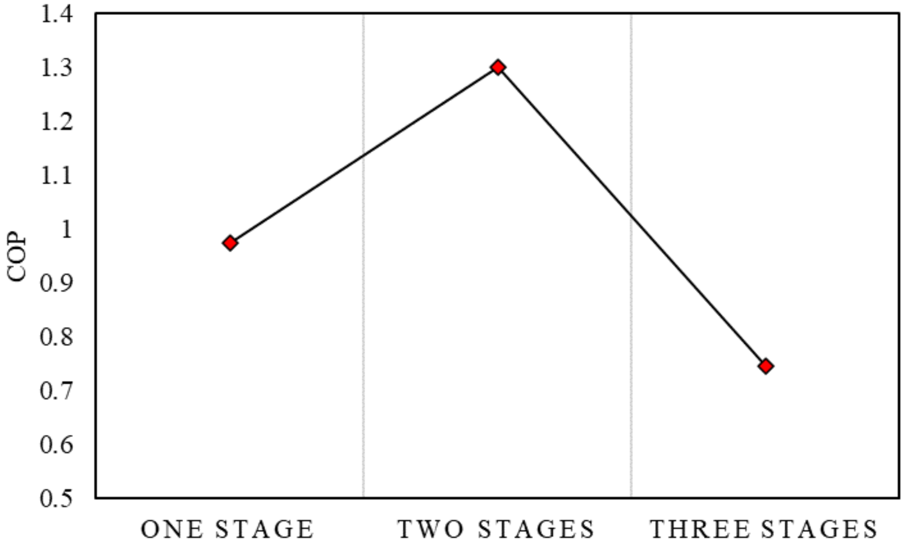

Figure 4- COP of the desiccant cooling system with different numbers of stages.

3.2 Impact of Solar Collector Type

This section investigates the performance of the solar-assisted desiccant cooling system using various types of solar collectors. To provide a more accurate comparison, the area of all collectors is the same and equals 8 m^2. Other components have the same information as the preceding sections. Figure 5 presents the results of this section. According to the results, PVT collectors can improve the COP of the system which is followed by evacuated tube and direct absorption collectors. As the required thermal energy of the system is supplied with a solar collector and an auxiliary electrical heater, PVT solar collector can meet the demand both types of energy which is needed to run the system. So it is preferable to use PVT collectors in solar desiccant cooling systems.

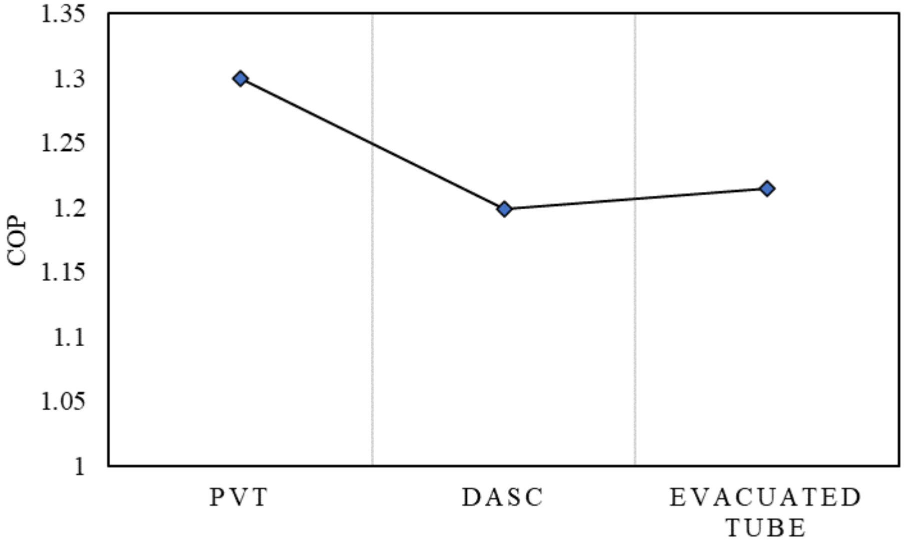

Figure 5- COP of the desiccant cooling system with different types of solar collectors

4 conclusion

In this study, a solar-assisted desiccant cooling system is presented and its performance in Jakarta, Indonesia's hot and humid climate is examined using the TRNSYS 18 software. To optimize and increase the system's COP, the impacts of solar collector's type and stages of desiccant and heat wheel are studied. According to the results, the suggested system with two sets of desiccant and heat wheels has a greater COP. Additionally, the system with one stage has a higher COP than the system with three stages. Moreover, because PVT solar collectors can provide both thermal and electrical energy to the system's auxiliary electrical heater, these collectors can achieve a greater COP. The system's COP is 1.3 with PVT, 1.215 with the evacuated tube, and 1.199 with direct absorption solar collectors.

5 References

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