INTERNATIONAL JOURNAL of RENEWABLE ENERGY RESEARCH
G. Y. Abusaibaa et al., Vol.13, No.4, December, 2023

Energy Efficiency Enhancement of Solar-Powered PV Cooling System with PCM Storage Tank

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Received: 01.05.2023 Accepted:22.06.2023

Abstract- The energy consumption of air conditioning systems has been rising over time. The adoption of solar-powered cooling technologies is being considered as a solution since they efficiently employ the energy that is currently available. In this work, the effectiveness of a phase change material (PCM) storage tank-connected vapour compression cooling system powered by photovoltaic (PV) energy were examined. The study focused on PV vapour compression with a PCM storage tank and an air-conditioned space chilled by ice gel circulation, a transparent membrane/desiccant, and fan coil dehumidification. The study used the TRNSYS, TRNBuild, and EES programmes to determine the best indoor temperature and humidity for a PV-powered vapour compression cooling system. The first simulation was conducted for the room without cooling, which reached a temperature of 32.58°C at 4146 hours of the year (June) Following that, the simulation for the developer's PV-powered vapour compression cooling system was run, and the coefficient of performance (COP) was calculated. It is noteworthy that the heat pump operates for 9 hours, while the system operates for 24 hours, depending on the cooling requirement, achieving room temperatures of 22.3 °C at 414 hours of the year. The relative humidity inside the building with the cooling system was approximately 59.2%. In addition, the lowest room dew point temperature was 14.9 °C at 4144.50 hours of operation. Moreover, at the same operating time, the system has a higher COP of 13.3. Overall, combining a vapour-compression air conditioning system with PCM storage improves system performance. This study utilised a comprehensive approach to assess the efficacy of a photovoltaic-powered vapour compression cooling system connected to a storage tank containing phase change material. Various methodologies and techniques were employed for this purpose, such as TRNSYS, TRNBuild, and EES software. The COP of the developed PV-powered vapour compression cooling system was calculated through simulation. The results have implications for addressing the rising energy consumption of air conditioning systems. The study examines the potential of a PV-powered vapour compression cooling system as a solution to the increasing energy demands for cooling. The results suggest a potential alternative to traditional air conditioning systems that could reduce energy consumption and promote sustainability in the built environment.

Keywords PV Panels, Ice gel, Chilled Ceiling, TRNSYS, TRNBuild.

1. Introduction

The global building sector accounts for a significant proportion, up to 40%, of final energy use. Data from authoritative sources indicates that a large portion of this energy is utilized for cooling and air conditioning purposes [1, 2]. The predominant technology for air conditioning is vapor compression systems, which are known to be energy-intensive and can contribute to environmental problems such as greenhouse gas emissions and heat waste . One approach to mitigating these concerns is to integrate alternative energy components into vapor compression systems [3,4]. However, the intermittent nature of solar radiation presents a challenge to the adoption of solar power systems [5,6]. The world's rapid population growth in recent years has driven an increase in demand for electric power, leading to heightened environmental pollution [7,8]. This pollution exacerbates global warming by increasing carbon emissions resulting from the combustion of fossil fuels, negatively affecting the ozone layer [9,10]. The net result is detrimental changes in the climate, including fluctuations in temperature and humidity [11], leading to negative consequences on the environment and human health. Wherefore, this section presents an extensive literature review of the latest methodologies aimed at providing solar air conditioning systems to cool buildings and predicting retrofit scenarios. Both deterministic and data-driven approaches are categorised and analysed in detail. This section takes as its springboard the concept that the lack of accurate information regarding the impact of retrofitting actions is one of the barriers preventing the widespread application of solar air conditioning system strategies worldwide.

Morttezapour et al. [12] conducted an examination of the output of a drier for saffron processing under the Qaen climatic conditions in Iran. Using the PV air collector has been shown to reduce energy usage by about 33%. The maximum specific moisture extraction rate was found to be 1.16 kg/kWh, yielding an airflow rate of 0.016 kg/s at a temperature of 60 °C and a drying efficiency of 72%.

In recent decades, the demand for energy to power refrigeration and air conditioning systems has steadily increased. This trend is expected to continue, with global energy demand and CO2 emissions projected to increase by 60% by 2030 compared to the beginning of the century [13, 14]. The largest contributor to this demand is the cooling load. Conventional vapor compression chillers require electricity from high-quality energy sources to operate, which is produced from non-renewable resources. To address these challenges, it is important to consider the strong correlation between the cooling load and the availability of solar energy during the summer months. As such, solar-powered cooling technologies present an attractive solution to meet the demand for cooling while utilizing a clean and renewable energy source.

Rahdar et al [15] simulated the performance of an ice thermal storage system and a PCM tank using a vapor compression air conditioner. The ice thermal energy storage system had a lower power consumption and CO2 emissions than the traditional system by 4.59 percent and 17.8 percent. Moreover, it had lower power consumption and CO2 emissions by 7.58 percent and 27.2 percent than the PCM system.

Beck et al. [16] observed that storing excess solar electricity generated by photovoltaic (PV) systems in refrigerators and freezers resulted in energy savings of up to 85% compared to a reference system. This suggests that the development of solar-powered air conditioning systems holds great promise for commercialization, provided that battery storage can be effectively replaced by ice thermal energy storage.

Axaopoulos et al. [17] studied a self-contained, eco-friendly ice-making system that operates without a battery and relies solely on solar energy. It utilises ice energy storage, making it maintenance-free and suitable for use in areas with limited access to energy. The system controller ensures efficient operation with almost perfect solar energy utilization, resulting in a compressor power efficiency of approximately 9.2%. This is achieved by facilitating smooth compressor startups and enabling low-temperature operation.

Salilih et al (a) [18] and Salilih et al (b) [19] investigated a solar refrigeration system that involved a DC compressor directly coupled to a non-tracking PV power source. The system's operating point is determined on the I-V plane, and the refrigeration cycle's COP is approximately 2.25 at low compressor speeds and 1.85 at high speeds. The compressor's minimum rotational speed of 1800 rpm requires an estimated radiation intensity of 315 W/m2. They also examined the impact of evaporator and condenser operating pressures on the performance of a directly linked variable speed solar refrigeration system.

Yongfeng et al. [20] studied the static ice refrigeration air conditioning system was evaluated, achieving an average photoelectric conversion efficiency of 11.76% and an average ice production of 52.56 kg. However, the system's energy efficiency (η) was found to be relatively low at 7.65%, primarily due to the ice making efficiency being around 50.19%. These results highlight the need for improving the efficiency of the ice making process to enhance the overall energy efficiency of such systems.

Han et al. [21] conducted a study on an integrated control strategy for a solar cooling system that utilized a PV system without a battery. The research showed that the photoelectric conversion efficiency improved by 83.7%, and the coefficient of performance COP reached 0.263. The compressor was operational continuously when the instantaneous irradiance exceeded 143 W/m2.

Li et al. [22] conducted a study on a 3 HP solar-powered air conditioning system that operates without batteries. The system utilizes ice thermal storage to store solar energy and employs a variable speed compressor and a maximum power point tracking (MPPT) controller. Experimental results have shown that the system exhibits good ice-making performance, reliable operation, and improved utilization of available solar energy. The system achieved its highest coefficient of performance (COP) of 0.289 when the cumulative daily total radiation in Kunming, China, was 18.2 MJ/m^2.

This research's importance lies in its potential to offer an eco-friendly approach to cooling buildings utilizing solar energy, given the increase in air conditioning systems' energy usage and the need for clean electric energy. The findings can address the challenges of high pollution and the scarcity of clean electric energy by exploring solar-powered cooling technologies.

The photovoltaic vapour compression cooling system has demonstrated great potential for sustainable and environmentally friendly refrigeration. However, its dependence on solar radiation and the high cost of battery storage present significant limitations. Therefore, researchers have focused on developing alternative methods of energy storage, with thermal storage emerging as a more economical option. Further research is needed to develop effective storage materials and tanks to optimise the use of photovoltaic refrigeration systems. In this study, was developed a mixture of materials water, glycerin, and ethylene glycol using the EES programme and tested it practically, and the results were promising. This mixture has a lower freezing point than water alone, and it has a higher thermal conductivity than glycerin or ethylene glycol alone. Moreover, this mixture is relatively inexpensive compared to other mixtures.

2. Methodology

2.1. Solar PCM Cooling System Design

The project was This study was limited to the development and evaluation of the energy performance of a heat pump system with a PCM storage tank. The solar PCM cooling system consists of various components which include: a compressor, a condenser, evaporator, chilled ceiling, water pumps, economizer, throttling valves, and photovoltaic cells (PV) with a PCM storage tank. The parts of the solar PCM cooling system are shown in Figure 1.

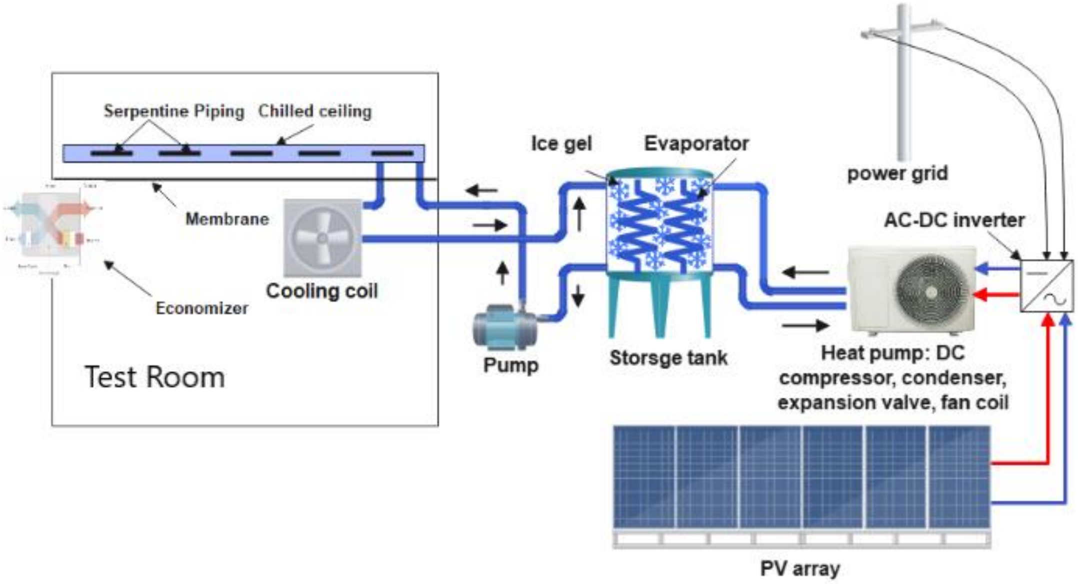

Figure 1. Solar PCM cooling system.

The conventional systems with solar PCM cooling systems has lower coefficient of performance (COP). The idea behind this work is the use of a chilled ceiling with fan coil and a PCM storage tank in the Solar PCM cooling system, which will create operational conditions that allow the use of the Solar PCM cooling system in solar cooling devices to improve the coefficient of performance (COP). After that, the capabilities available in the Environment TRNSYS Simulation program will be used to develop the novel design of the solar cooling system and take the optimum parameters. Finally, one of the goals of developing the solar PCM cooling system in this study is to estimate COP and solar friction. The flow diagram of the PCM cooling system is shown in Figure 2 by the TRNSYS simulation program.

The Several assumptions were used to evaluate the performance of the solar cooling system in a tropical climate. First, the simulation was carried out for the month of June. Second, a time step of one hour was selected to capture the dynamic behaviour of the cooling system accurately. Third, weather data for Kuala Lumpur, Malaysia, was utilised to provide accurate information on the ambient conditions during the simulation period. Fourth, the DC air conditioning system used in the study had a capacity of 1.5 ton. Fifth, in this study, the cooling system was used with PV panels to demonstrate that a solar cooling system can be directly operated by DC power from solar panels without needing an inverter, controller, or batteries. In this study, three PV systems containing 4, 5, and 6 solar panels were simulated, with each solar PV cell producing an electrical power of 275 W. Finally, the compressor and chilled water system operated for 9 and 24 hours, respectively, to assess their impact on the system's overall efficiency. These assumptions were carefully considered to provide reliable and relevant findings for the study's objectives.

The simulation was conducted at the locationof Kuala Lumpur, 2o 55" N, 101o 46" E and it is situated at an altitude of 533 meters. The test room was constructed in compliance with Malaysian building standards, and it has a volume of (2.7 x 2.7 x 2.7) cubic meters, accommodating a single individual. Figure 3 shows the detail and thickness of the layers of the walls.

The structural characteristics of the room under analysis are intricate and have important implications for its thermal behavior. Specifically, the two sloping ceilings in the room are each composed of two layers, an insulator and a steel side, with thicknesses of 0.075 m and 0.002 m, respectively.

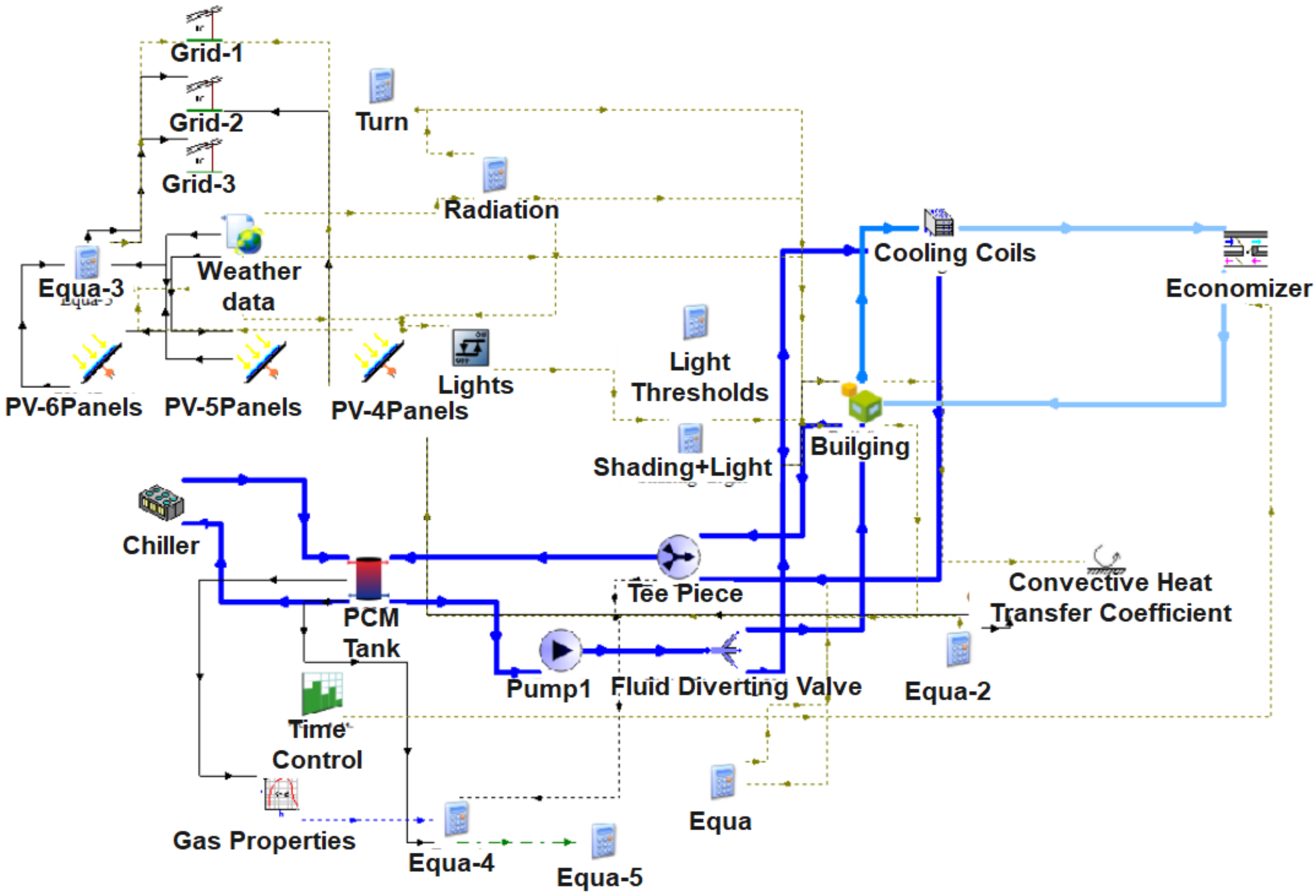

Figure 2. The flow diagram of the PCM cooling system.

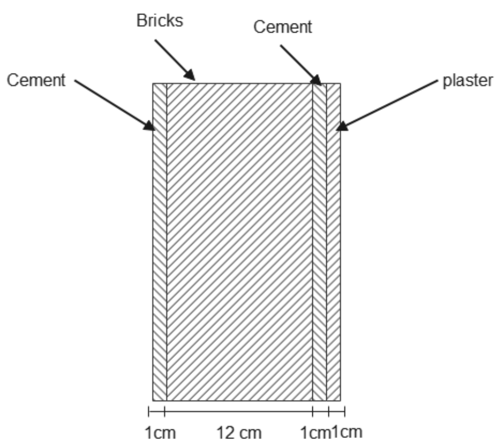

Figure 3. The detail and thickness of the layers of the walls.

These layers cover a surface area of 8 m2 on each side at an angle of 25 degrees to the horizon, resulting in a complex geometric arrangement. Furthermore, the direction of the first roof is E_270_25, while the second roof faces W_90_25, which has important implications for how the roofs are exposed to solar radiation throughout the day. Understanding the thermal behaviour of these roofs is critical for designing appropriate insulation strategies and controlling the indoor temperature and energy consumption of the room.

The TRNSYS software was employed to ascertain the optimum parameter for the length of the heat exchanger tubes situated within the storage tank. The optimal length for maximising heat transfer efficiency and overall system performance was determined through intensive simulations and analysis. The process of critical evaluation facilitated the optimisation of the design of the heat exchanger tubes and the enhancement of the effectiveness of the storage tank in the cooling system.

The PCM (phase change material) tank that is specially designed to enhance the heat exchange efficiency between the PCM (in this case, ice gel) and a refrigerant fluid. The tank used in the theoretical is shown in Figure 4, and the specifications of the first and second coils in the storage tank are provided in Table 1.

The twin coils in the storage tank play a crucial role in facilitating the transfer of heat between the PCM and the refrigerant fluid, thereby enabling efficient thermal energy storage and retrieval. The dimensions of the storage tank and the coils are shown in Figure 5, which provides a detailed visual representation of the tank's structural characteristics. This theoretical setup is critical for investigating the thermal behavior and performance of PCM-based energy storage systems and can provide valuable insights into the design and optimization of such systems for various applications.

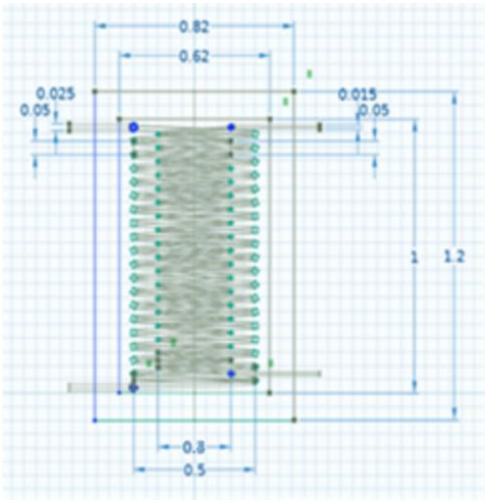

Figure 4. Dimensions of the first and second heat exchangers in the storage tank.

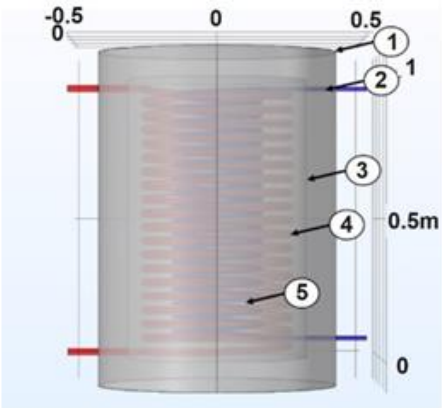

Figure 5. Specifications of the first and second heat exchangers in the storage tank.

In order to model a radiant cooling system, a chilled ceiling is employed, which consists of an "active layer." The term "active" refers to the fact that the layer includes pipes filled with fluid, which are responsible for extracting heat from the ceiling. The specific heat coefficient of PCM Ice Gel is determined to be 3.287 kJ/kg K. The pipe spacing, measured from centre to center, is 0.1 m, while the pipe has an outside diameter of 0.02 m and a wall thickness of 0.002 m. The conductivity of the pipe wall is 1.26 kJ/h mK. These parameters are crucial to accurately simulating the performance of the chilled ceiling system and obtaining reliable results.

The cooling coil and fan coil are critical components of heating, ventilation, and air conditioning (HVAC) systems used in buildings to regulate indoor air temperature, humidity, and air quality. Fan coils are integrated into the system not only to offer cooling but also to absorb moisture while maintaining thermal balance inside the room. This integration optimises the indoor air quality to create a comfortable and healthy environment for the occupants while improving energy efficiency. By absorbing moisture from the air, the fan coils help prevent the growth of mould and bacteria, further enhancing the air quality inside the building.

The design of the room-conditioning system is a crucial factor in ensuring optimal indoor air quality and thermal comfort. To this end, the integration of an economizer component is a common approach to achieving energy-efficient ventilation while maintaining high indoor air quality. The economizer component functions by ventilating the room with the option of mixing fresh outdoor air with the return air, thereby reducing the energy required to cool it. This approach maximises the amount of thermal energy retained within the room, thereby reducing energy consumption and improving overall energy efficiency. Figure 6 provides a visual representation of the economizer component, which is a key component of the room conditioning system and plays a crucial role in maintaining a healthy and comfortable indoor environment while minimising energy consumption.

The process of choosing the PCM was a consequence of a thorough examination of the physical characteristics of prospective component materials. The EES programme was utilised to conduct a comprehensive analysis and rigorous testing to identify the ingredients that demonstrated favourable attributes for our intended application. Through the utilisation of the acquired data, the ingredient proportions were calculated to produce an ice gel blend that exhibits optimal characteristics for our refrigeration mechanism.

The PCM Ice Gel Materials used in the storage tank were designed using the EES program, which utilized a formula for mixing ingredients of water (92.5%), alcohol/methanol (2.5%), and glycerin (5%). The resulting thermal properties were then analysed and are presented in Table 2. This type of PCM material is commonly used in energy storage systems to store and release cooling energy. The addition of glycerin to the mixture can improve its thermal stability and prevent the PCM material from solidifying at lower temperatures, thus enhancing the overall efficiency of the storage tank. The EES programme allowed for a precise calculation of the appropriate mixture of ingredients to achieve the desired thermal properties of the PCM Ice Gel Materials, making it an effective and reliable choice for energy storage in various applications.

Simulations were conducted in the TRNSYS programme to evaluate the efficacy of the ice gel mixture. A comprehensive understanding of the performance of the ice gel was obtained through the analysis of its physical properties in these simulations. The simulations conducted yielded encouraging outcomes, validating the ice gel's efficacy in retaining ice and delivering cooling effects for a period of 24 hours in the experimental enclosure.

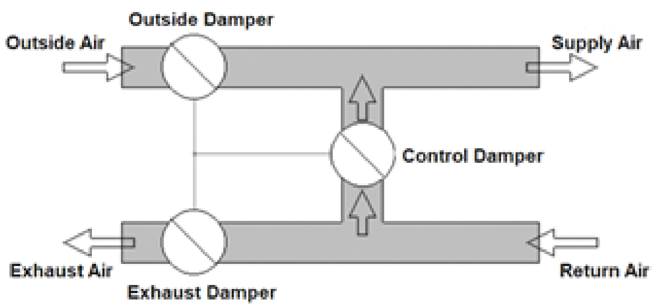

Figure 6. Air Side Economizer Schematic.

Table 1. The specifications of the first and second coils in the storage tank in figure 5.

Number	The part in the picture	Dimensions
1	Sheet	Thickness 1 mm
2	Insulation	Thickness 100 mm
3	Tank	Volume 0.19 m^3
4	Second coil	Length 28 m Number of turns 18
5	First coil	Length 28 m and Number of turns 22

Table 2. Thermal Properties of PCM Ice Gel Materials.

Materials	Thermal conductivity W/m.K	Heat Capacity kJ/kg.K	Density kg/m^3
Alcohol/ methanol	0.1983	2.535	786.3
Glycerin	0.2849	2.418	1259
Water	0.5948	4.183	997.1
Water (92.5%), Alcohol/ methanol (2.5%), Glycerin (5%), (PCM Ice Gel)	0.5694	4.054	1005

2.2. The Simulation Steps

In the first stage, the room was designed and built by the TRNBuild program, which is an assistant program that works with the TRNSYS simulation. The simulation process consists of the three main steps involved in simulating a dynamic building. The initial step involves inputting data from the building simulation and active system into the TRNSYS Simulation Studio. The second step is to process the data for each time step by exporting and importing it between TRNSYS Simulation Studio and TRNBuild programs, resulting in final results. The third step involves presenting the results through a plotter or tables. Thereafter, the system's refrigerant cycle was designed based on first and second laws of thermodynamics in the calculation of fluid parameters (P, T, m, V, etc.) at all stages of the system.

Then, the solar PCM cooling system was designed by the TRNSYS and EES programs. Next, the required amount of thermal energy removed from the system is calculated, thermal balance calculations were performed. In the second stage, which depends on stage 1, the amount of thermal energy to be removed from the system is calculated. Where a solar PCM cooling system design is conducted to provide the necessary cooling for the project. After completing the design of the room and solar heat pump system, we designed a storage tank and ice gel in TRNSYS and EES respectively, with a heat exchanger suitable for heat exchange between the ice gel cycle and a refrigerant fluid.

3. Results and Discussions

The simulation was conducted over the course of a month (June) to evaluate the performance of a solar cooling system for space cooling. The results indicate that the system was able to maintain a maximum and minimum cooling temperature of 24.52 °C and 22.3°C, respectively. The use of a solar cooling system offers several advantages over traditional cooling systems, including increased efficiency and reduced energy consumption. The simulation results, depicted in Figure 7, show a simulation time of 4144.50 [hr], providing a comprehensive analysis of the system's performance over an extended period. These findings support the use of solar cooling systems as a viable solution for space cooling in various applications.

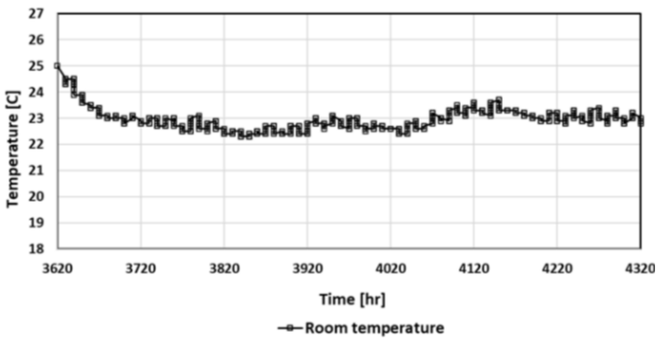

Figure 7. Comparison of room temperature of the three options.

In the simulation, it was found that the solar cooling system was highly effective in regulating the relative humidity in the room. At time zero, the relative humidity was 85%. After running the simulation and the system, the levels of maximum and minimum relative humidity were recorded at 65.5% and 59.2%, respectively. The solar cooling system was able to absorb moisture from the room during the 4144.50 hours of operation, as shown in Figure 8, resulting in a significant decrease in relative humidity.

Malaysia's tropical climate, with its consistent heat and humidity, may render ASHRAE 55's recommended indoor design temperature and relative humidity unsuitable. DOSM has proposed alternative guidelines for indoor temperature and humidity in design. According to DOSM, indoor temperatures should be kept between 23°C and 26°C, and the recommended relative humidity should be between 60% and 70% [23].

Since the humidity level in the Malaysian environment can sometimes reach as high as 99%, the solar cooling system presents itself as an efficient solution for controlling relative humidity in indoor spaces. Thus, the system has the potential to provide a comfortable and healthy indoor environment for occupants.

The results obtained from the simulation of the solar cooling system show that the system is highly effective in reducing the dew point temperature within the room. As depicted in Figure 9, the maximum dew point temperatures at the start of the running of the system were 21.8 °C, and the minimum dew point temperatures recorded after a few hours of running the system were 14.9 °C, over the 4144.50 [hr] simulation period. This outcome highlights the efficiency of the system in regulating the relative humidity of the room, as corroborated by the low relative humidity levels shown in Figure 10. The low dew point temperature obtained is an indication of the high moisture absorption capability of the solar cooling system, making it a suitable solution for creating a comfortable indoor environment for occupants, especially in regions with high humidity levels.

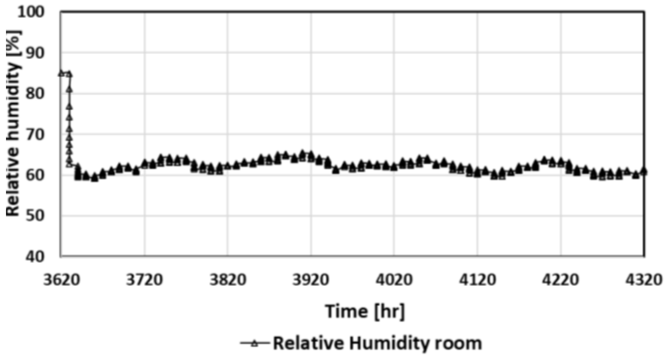

Figure 8. The relative humidity inside the room.

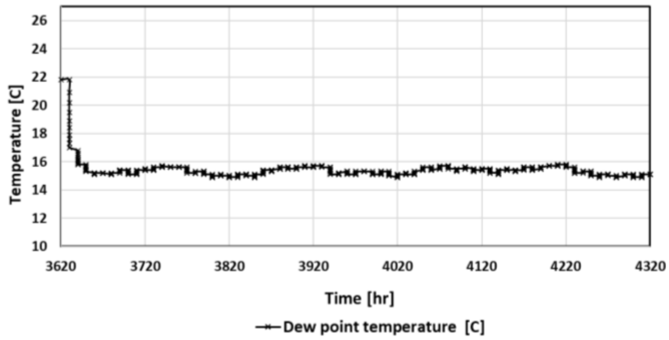

Figure 9. Dew point temperature inside the room.

The outcomes of the TRNSYS software simulation are analysed in relation to Figure 10. The figure presents a graphical representation in the form of a bar chart that illustrates system parameters associated with the yearly functioning of the system. The objective of the yearly simulation was to investigate the electrical power generation potential of four, five, and six photovoltaic panels of the solar cooling system over the course of a year, the quantity of electricity consumed from the grid, and the annual solar fraction.

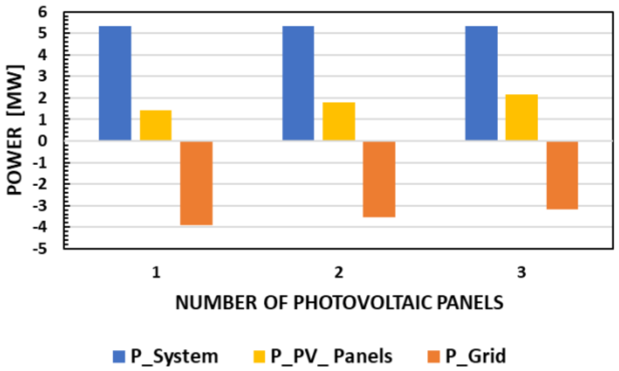

Figure 10 Annual electricity consumed by the system, electricity generated from the photovoltaic panels, and electricity withdrawn from the grid with varying numbers of photovoltaic panels (ranging from 4 to 6 panels).

The bar chart displays annual electricity consumption, electricity generation from different numbers of photovoltaic panels, and grid electricity withdrawal. The total annual photovoltaic generation for four, five, and six panels were 1.419212961 MW, 1.803627473 MW, and 2.164352968 MW, respectively. Furthermore, the yearly consumption of electricity from the power grid when using four, five, and six photovoltaic panels in the solar cooling system was documented as 3.926475261 MW, 3.542060749 MW, and 3.181335254 MW, respectively, while the annual electricity cost for the solar cooling system was 5.34274 MW.

Additionally, Figure 11 shows that the annual solar fraction of the four, five, and six photovoltaic panels of the solar cooling system was found to be 26.5%, 33.7%, and 40.5%, respectively.

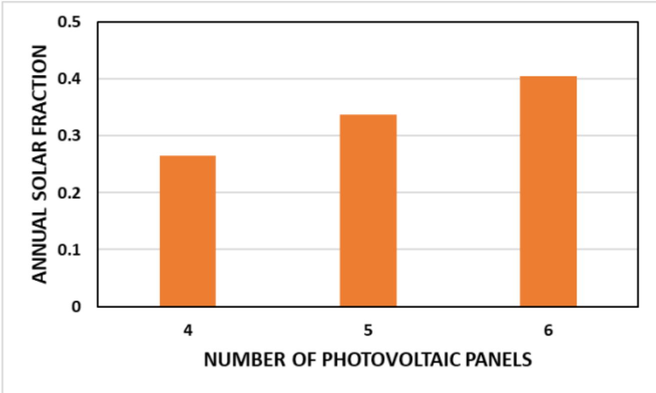

Figure 11 Annual solar fraction of the solar hybrid vapor compression cooling system with varying numbers of photovoltaic panels (ranging from 4 to 6 panels).

This exhaustive examination facilitates a definitive comprehension of the yearly production of the six photovoltaic panels under the climatic conditions prevalent in Malaysia.

2. Conclusion

It is possible to conclude that using a photovoltaic (PV)-powered vapour compression cooling system linked to a phase change material (PCM) storage tank improves the performance of an air conditioning system. The study utilized TRNSYS, TRNBuild, and EES programs to simulate and optimize the system's parameters, including indoor temperature and humidity. The simulation results showed that the PV-powered vapour compression cooling system with a PCM storage tank achieved room temperatures of 22.3°C and a relative humidity of 59.2% while operating for 24 hours. The system also had a higher coefficient of performance (COP) of 13.3 compared to conventional systems, indicating better energy efficiency. Furthermore, combining a vapour-compression air conditioning system with PCM storage tanks improves system performance by allowing for efficient thermal energy storage and release.

This research highlights the potential of solar-powered cooling technologies as a sustainable solution to reduce energy consumption in air conditioning systems. Further research can be conducted to optimize the system's design and components and explore its scalability for larger buildings and applications. Overall, the findings of this study have significant implications for the development and implementation of energy-efficient and sustainable cooling systems in the future.

Acknowledgements

The authors would like to thank DPK-2021-007 Dana Padanan Kolaborasi (DPK), Universiti Kebangsaan Malaysia for support of this work.

References

[1] IEA (International Energy Agency), 2013. Technology roadmap. Energy efficent building envelopes. Oecd Available online, http://dx.doi.org/10.1007/ SpringerReference_7300.

[2] I. Hamilton, H. Kennard, O. Rapf, J. Kockat, S. Zuhaib, T. Abergel, M. Oppermann, M. Otto, S. Loran, and N. Steurer, Global Status Report for Buildings and Construction: Towards a Zero-Emission. Efficient and Resilient Buildings and Construction Sector, 2020.

[3] S. Z. Ilyas, A. Hassan, and H. Mufti, Review of the renewable energy status and prospects in Pakistan. International Journal of Smart Grid, 2021. 5(4): p. 167-173.

[4] I. M. Opedare, T.M. Adekoya, and A.E. Longe, Optimal sizing of hybrid renewable energy system for off-grid electrification: A case study of University of Ibadan Abdusalam Abubakar Post Graduate Hall of Residence. Int. J. Smart Grid-ijSmartGrid, 2020. 4(4): p. 176-189.

[5] K. Amara, A. Fekik, D. Hocine, M.L. Bakir, E.-B. Bourennane, T.A. Malek, and A. Malek. Improved performance of a PV solar panel with adaptive neuro fuzzy inference system ANFIS based MPPT. in 2018 7th international conference on renewable energy research and applications (ICRERA). 2018. IEEE.

[6] D. Haji, and N. Genc. Fuzzy and P&O based MPPT controllers under different conditions. in 2018 7th International Conference on Renewable Energy Research and Applications (ICRERA). 2018. IEEE.

[7] G. S. Rao, B.S. Goud, and C.R. Reddy. Power Quality Improvement using ASO Technique. in 2021 9th International Conference on Smart Grid (icSmartGrid). 2021. IEEE.

[8] F. Ayadi, I. Colak, I. Garip, and H. I. Bulbul. Impacts of renewable energy resources in smart grid. in 2020 8th International Conference on Smart Grid (icSmartGrid). 2020. IEEE.

[9] D. Urge-Vorsatz, L. F. Cabeza, S. Serrano, C. Barreneche, and K. ¨ Petrichenko, "Heating and cooling energy trends and drivers in buildings," Renewable and Sustainable Energy Reviews, vol. 41, pp. 85–98, 2015.

[10] AE Kabeel, "Performance improvement of a hybrid AC system using the indirect evaporative cooler with internal baffle as a precooling unit", Alexandriya Engineering Journal, (2017), dx.doi.org/10.1016/j.aej.2017. 04.005.

[11] K. Sevinc, K., Gungor, A." Güneş Enerjisi Kaynaklı Soğutma Sistemleri ve Bu Alandaki Yeni Uygulamalar, Mühendis ve Makina", pp. 53- 635, 59-70, 2012.

[12] H. Mortezapour, B. Ghobadian, S. Minaei, and M.H.J.D.T. Khoshtaghaza, Saffron drying with a heat pump–assisted hybrid photovoltaic–thermal solar dryer. Drying Technology, 2012. 30(6): p. 560-566.

[13] R. Gugulothu, N.S. Somanchi, H.B. Banoth, and K. Banothu, A review on solar powered air conditioning system. Procedia Earth and planetary science, 2015. 11: p. 361-367.

[14] P. Bermejo, F.J. Pino, and F. Rosa, Solar absorption cooling plant in Seville. Solar energy, 2010. 84(8): p. 1503-1512.

[15] M. H. Rahdar, A. Emamzadeh, and A. Ataei, A comparative study on PCM and ice thermal energy storage tank for air-conditioning systems in office buildings. Applied Thermal Engineering, 2016. 96: p. 391-399.

[16] M. Beck, K. Müller, and W. Arlt, Storing surplus solar energy in low temperature thermal storage for refrigeration applications. Energy and buildings, 2016. 122: p. 192-198.

[17] P. J. Axaopoulos, and M. P. Theodoridis, Design and experimental performance of a PV Ice-maker without battery. Solar Energy, 2009. 83(8): p. 1360-1369.

[18] E. M. Salilih, and Y.T. Birhane, Modelling and performance analysis of directly coupled vapor compression solar refrigeration system. Solar Energy, 2019. 190: p. 228-238.

[19] E. M. Salilih, Y.T. Birhane, and N.H. Abu-Hamdeh, Performance prediction of a solar refrigeration system under various operating pressure of evaporator and condenser. Solar Energy, 2020. 209: p. 485-492.

[20] Y. Xu, X. Ma, R.H.E. Hassanien, X. Luo, G. Li, and M. Li, Performance analysis of static ice refrigeration air conditioning system driven by household distributed photovoltaic energy system. Solar Energy, 2017. 158: p. 147-160.

[21] Y. Han, M. Li, Y. Wang, G. Li, X. Ma, R. Wang, and L. Wang, Impedance matching control strategy for a solar cooling system directly driven by distributed photovoltaics. Energy, 2019. 168: p. 953-965.

[22] G. Li, Y. Han, M. Li, X. Luo, Y. Xu, Y. Wang, and Y. Zhang, Study on matching characteristics of photovoltaic disturbance and refrigeration compressor in solar photovoltaic direct-drive air conditioning system. Renewable Energy, 2021. 172: p. 1145-1153.

[23] M. Standard, MS 1525 Code of practice on energy efficiency and use of renewable energy for non-residential buildings. Department of Standards Malaysia, 2001.