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Solar water heating based on Bellville weather conditions in winter

Zamavangeli Mdletshe*, Velaphi Msomi and Ouassini Nemraoui

Abstract

Hot water supply is a daily necessity for various purposes ranging from industrial to domestic usage. However, the availability of hot water supply is dependent on reliable energy systems to heat the water. The load shedding plan declared the energy crisis in South Africa. Therefore, exploring alternative energy methods for hot water supply is critical, especially renewable energy resources. The use of natural resources such as solar energy to heat water is highly impacted or limited by the resources and environmental conditions existing at the area of interest. The use of the solar water heating system based on Bellville; South Africa was the undertaken study. This study reports on the experimental investigation that was conducted on a 50 L water geyser, which was solar-based. The test rig that was constructed and tested was an active solar water heating system. It was tested over a period of 10 days under the environmental conditions experienced in mid-winter season of South Africa. A 20 tubed evacuated tube collector unit was used, and it was found that in mid-winter of the highest water temperature that the system could reach was above 65 °C and the lowest was 30 °C. Intriguing outputs were found in the study which revealed that, on the days that yield the highest solar irradiation did not necessarily produce the hottest water temperature. Therefore, scrutinizing the impact of other parameters that contributed to the overall water temperature output was necessary. From the tests it was observed that the wind velocity together with other environmental parameters effectively had an impact on the water temperature yield by an evacuated tube system.

Keywords Evacuated tube collector, Solar heated water, Solar energy, Solar harvesting

Introduction

The water-energy nexus has been trending over the decade in attempt to address the respective ongoing crisis (Kılkış et al., 2019). This crisis requires collective effort for a better solution to it. In our daily lives we need energy for various purposes for domestic use and for various industrial energy applications (Arif et al., 2022; Guo & Yang, 2021; Sanguinetti et al., 2021). Hot water is one of the of the energy applications which is a daily necessity, which requires the two primary resources, energy, and usable water. Different water heating systems were studied (Long et al., 2021; Martin-Escudero et al., 2019; Weaver et al., 2022). However, in this study focus is on the production of hot water or hot water yielding systems that uses solar renewable energy. There are various kinds of solar water heating systems, such as the flat plate and the evacuated tube system. Over the years attempts to improve solar water heating systems have been made, so that technical literature can, and finer novelty can be attained, so that implementation on a large scale can be possible.

Maraj et al., 2019, conducted an experimental study on a small-scale evacuated tube collector unit situated in Tirana. The solar collector unit had an aperture area of 1.476 m^2 was used. When they analysed the energy performance of their system, they found the annual solar irradiation to be 2.22kWh/year at annual mean ambient

*Correspondence:
Zamavangeli Mdletshe
mdletshezamavangeli@gmail.com
Mechanical Engineering Department, Cape Peninsula University of Technology, Cape Town, South Africa

air of 17 °C. In addition, they discovered that the annual efficiency of the collector to be 62%.

Naji et al. (2019), conducted a comparative experimental study that investigated the performance of two similar evacuated tube test rigs, for solar water heating, subjected to varied testing conditions. In this study it was found that for both setups, the water quantity in the storage tank affects the rate at which the water is heated and the efficiency of both rigs. It was assessed and concluded that the thermosyphon system is suitable for domestic use.

Araya et al., (2017), investigated the potential use of flat-plate solar water collector (FPSWC) for the country Chile. They assessed the energy performance using a model to optimize the life cycle savings (LCS). In conducting their study, they considered the solar availability, the energy requirements, solar harvesting area, water storage volume and FPSWC installation costs. The parameters considered were to analyse the financial aspect of implementing the FPSWC. They found that the FPSWC saved 6.85 times on energy when different analysis methods to estimate the LCS. Lamosa et al. (2021) conducted a similar study on flat plate photovoltaic collector, their study included the life cycle analysis and energy efficiency of the flat plate photovoltaic collector, which was more than 60% when it was simulated.

Previous studies have considered viability of cost and environmental factors (Singh et al., 2022; Yanhua et al., 2019). Therefore, in the process of producing hot water, energy systems that are environmentally friendly are advisable, especially renewable energy dependant systems. One of the processes of heating water, is using solar energy which can be either be from direct solar rays or indirect use of solar rays to bring about the temperature difference to the subjected water (Gaonwe et al., 2022; Pathak et al., 2022).

When harvesting solar rays for the purpose of heating water, apart from solar irradiation, various environmental conditions are critical to the performance of the solar harvesting system. Studies previously conducted have attempted to analyse the impact of the different environmental conditions, such as the wind velocity, humidity, and outdoor temperature (Abu Mallouh et al., 2022; Kushwah et al., 2021; Tabarhoseini et al., 2022).

Studies like the current study have investigated environmental parameters impact on the performance of evacuated tubes solar water heating system-based at respective locations. Siuta-Olcha et al., (2021) conducted an experimental study on a 24 evacuated tube solar water heating system. They scrutinised the 3.9 m^2 solar collector test rig under Poland climatic conditions in the months of July and August. They observed for that period the average solar irradiation to be 3.1 kWh/(m^2.d) and mean temperature to be 19 °C, which yield an average monthly energy efficiency of 45.3% in July and 32.9% in August. In computing the energy efficiency, the parameters that were considered are the wind velocity, outdoor temperature, and solar irradiance.

Hayek et al., (2011) conducted a study over three months, November to January, under climatic conditions of Zouk-Mosbeh. Their observations were on two kinds of evacuated tube setup, the first setup was that of a standard glass in water collector of twenty tubes array and a heat pipe collector array. In their experiments they explode different tilted angles of the array at varied climatic conditions. They concluded that the heat pipes array had the best efficiency than the glass in water array.

Chow et al., (2011) performed an experimental and numerical study on the evacuated tube test rig system under Hong Kong climatic conditions. They assessed two types of solar water heaters applicable for domestic use, namely, the two-phase closed thermosyphon and single-phase open thermosyphon. Their evaluation was based on the daily thermal performance of the two studied test rigs. After the experimental observation they numerically validated that the two-phased system out-performed the single-phased system. In conducting the experiments, a 150 L storage geyser was used. The outdoor temperature was considered when the energy gain was computed using both experimental and simulated data inputs for the winter and summer periods.

Kyekyere et al., (2021) tested the evacuated tube collector under the environmental conditions of Juja, in Kenya. Their experiments were conducted from 9 am to 5 pm, in the period of January to February. They found that their test rig produced a maximum water temperature of 55 °C; when the outdoor temperature was 35 °C, wind velocity was 2.3 m/s on average and a solar irradiation of 1100 W/m^2.

Research gap and contribution

A considerable number of previous studies has focused on the technical aspect of enhancing the performance of the evacuated tube collector (ETC) units. However, the technical aspect is not the only input parameter that influences the output of this system. The output being the stored water temperature at the geyser after it had undergone solar harvesting as a mechanism of adding heat the stored water. The literature reviewed shows that, other parameters such as the environmental conditions can influence the water temperature output. However, the environmental conditions may vary by location and by seasonal weather conditions. Therefore, it was identified that for South Africa weather conditions have not

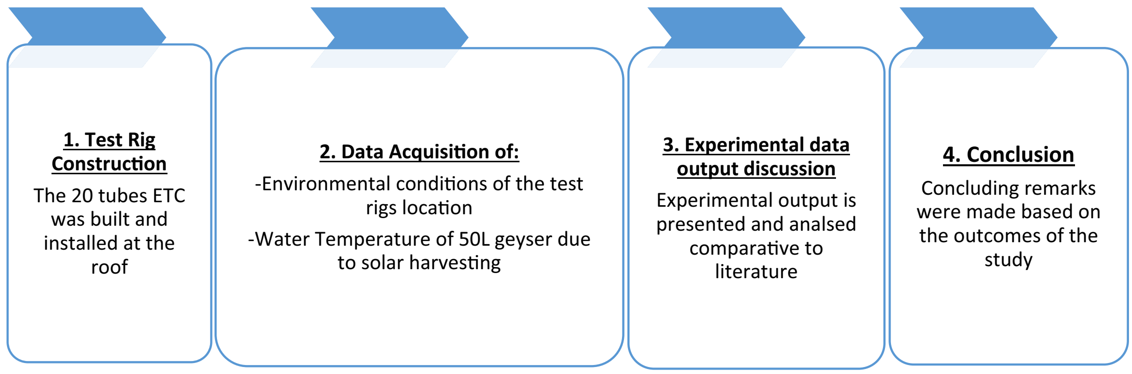

Fig. 1 Methodology followed for the experimental study

yet been assessed for the purpose of the ETC unit's performance. The experimental study took place on Bellville at the Cape Peninsula University of Technology in the Western Cape Province, 33.93035°S, 18.6391°E.

This study aims to experimentally demonstrate and analyse the impact of parameters such as the solar irradiance, outdoor temperature, and wind velocity on the water temperature output at the storage geyser when a twenty tubed ETC unit was used, under South African climatic conditions in winter. The experiments were conducted over a period of 10 days. Comparative remarks on the parameters against the water temperature output are presented in this article.

Research methodology

The method that used in this study was experimental. After, the research test rig had been constructed and the data acquisition system was put in place to capture the experimental data from the system, the following was done. Over 10 days in the mid-winter month, of July 2022, the water temperature data were captured. Therefore, a completed single test was over a day from sunrise to sun set. This was performed for subsequent 10 days. The water temperature of the water stored in the 50 L geyser was monitored concurrent to the environmental conditions data that were captured with the aid of a weather station. The aim of the study was to monitor

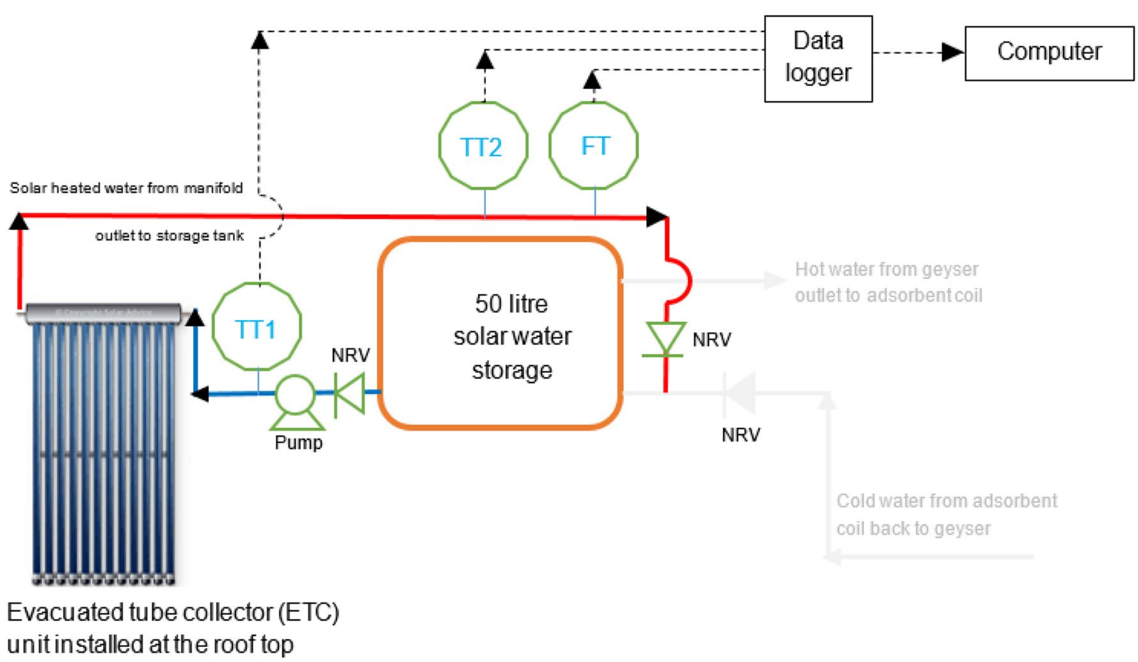

Fig. 2 Pipe and instrumentation diagram of the solar collector array testing rig

Fig. 3 The 20 evacuated tubed collector unit installed onto the roof

the water temperature of a 50 L geyser when solar water heating unit was used in mid-winter which was based on South Africa. The output data were then analysed to assess the impact that the (solar irradiation, outdoor temperature, and wind velocity) parameters had on the water temperature yield by the system. Figure 1 shows the research methodology that was followed in this study. The construction of the pipe network was fabricated using a 15 mm diameter copper pipe. The twenty evacuated tubes installed were purchased from the local, Bellville town, supplier manufactured by *Kwikot.* In the data acquisition phase picotechnology equipment were used, to monitor the water temperature and to monitor the weather conditions a weather station was used logging the solar irradiation, winds velocity, outdoor temperature. However, this study was, limited to experimental observations only. The data were discussed to highlight the impact of the environmental input parameters of Bellville.

Experimental setup apparatus

A PT104 data logger together with two PT100 sensors were used to monitor the water temperature throughout the day. The water flow was measured using the YF-S201 flow meter that was connected to the Arduino Uno for processing and then to the computer for live data capturing. These data were digitally logged on to the computer. For environmental conditions, the data acquisition system that was used was a weather station that logged

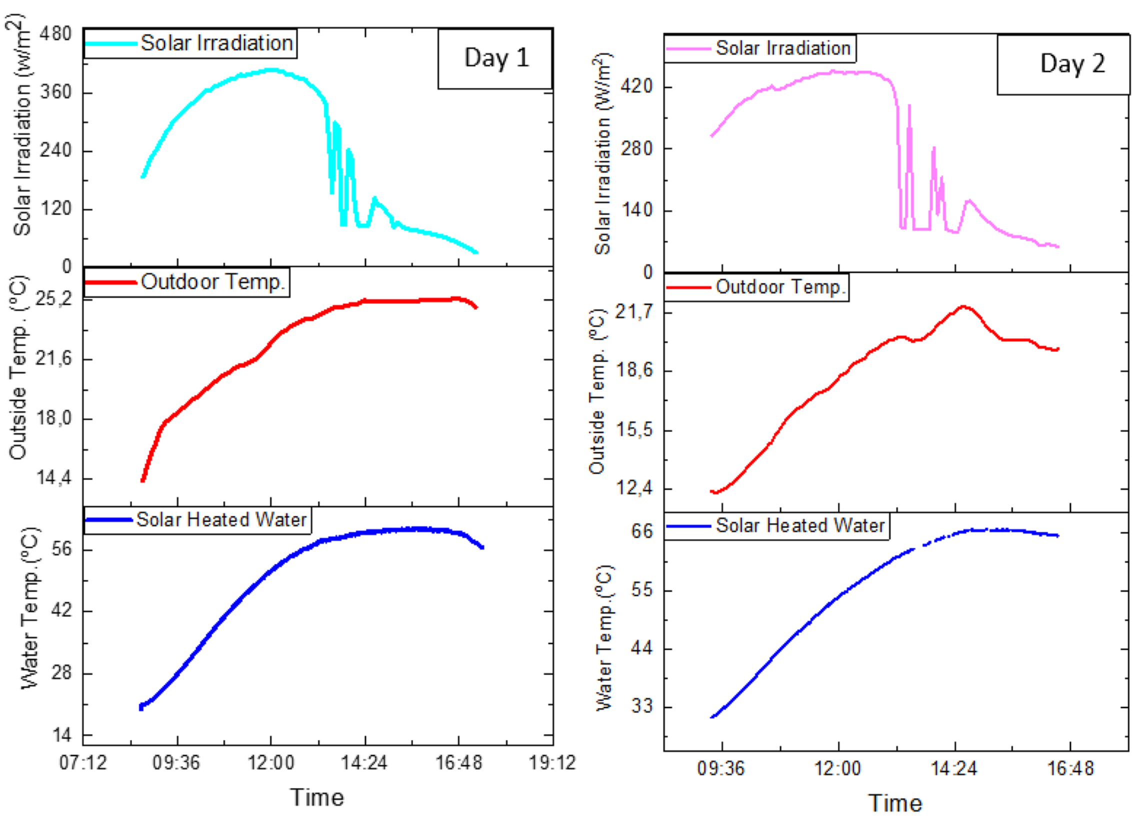

Fig. 4 Solar irradiation, outdoor temperature and solar heated water temperature for day 1 and day 2

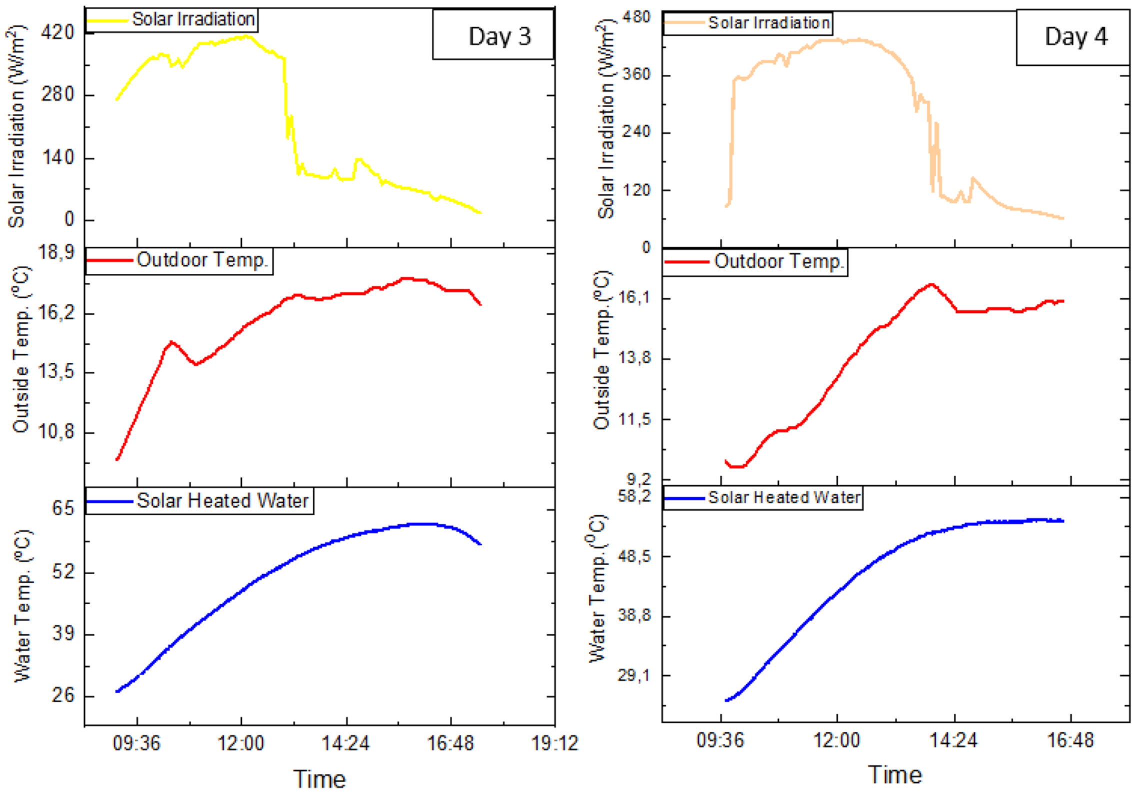

Fig. 5 Solar irradiation, outdoor temperature and solar heated water temperature for day 3 and day 4

various environmental parameters that were later used to discuss the experimental output of the system. These data were also digitally logged every 5 min of each day onto a memory card that was transferred into the computer for data processing. The 50 L storage geyser was situated indoors at the laboratory and the evacuated tube collector unit was placed outside at the roof of this laboratory. A special apparatus setup to monitor the flowrate of the working fluid, flowing through the manifold of the Evacuated Tube Collector (ETC) unit was prepared and used with the assistance of the Arduino Uno was put in place.

In Fig. 2 is the pipe and instrumentation diagram showing the overall test-rig setup prepared to conduct the experiments. The water pump used was electrically powered with a positive suction head to the pump. Only the centrifugal water pump and the data logging system, was electrically powered. The centrifugal water pump was used for water circulation, the data loggers was used for system monitoring and data capturing on the test rig. No water draw-offs existed in the system. The system was to monitor the water temperature output relative to the environmental conditions (Fig. 3).

Experimental results and discussion

In this section, the experimental outcomes that were observed over the 10 day mid-winter period will be discussed. Graphically, presented for each day (from day 1 to day 10) are the solar irradiation, outdoor temperature and the water temperature difference that was observed throughout the day. Discussions will be based on these three parameters and later other parameters such as wind velocity will be discussed for days that yield intricate system behaviour.

Similar previous studies show that when conducting experimental on the evacuated tube collector unit these are the documented outputs to date from various locations. These researchers assessed the impact due to some of the environmental parameters that were scrutinized in this study. (Kyekyere et al., 2021). Sharma et al., (2022) they observed a correlation between increasing solar irradiation and rising water temperature output due to solar irradiation. They observed this in a hybrid system of a ETC unit and a parabolic concentrated powered solar water heating unit. Therefore, this study also presents the

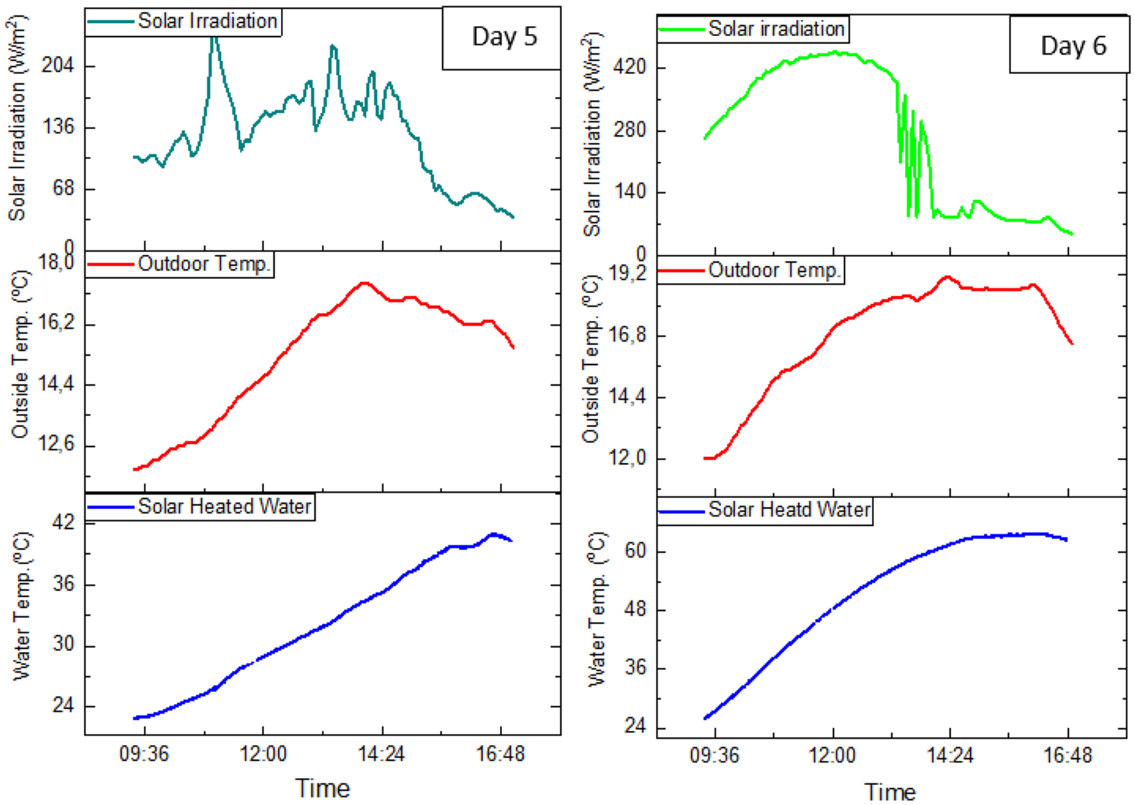

Fig. 6 Solar irradiation, outdoor temperature and solar heated water temperature for day 5 and day 6

performance of an ETC based on Bellville. This would give a guide of what to expect of an ETC unit operated at locations that distinguish similar environmental characteristics (Figs. 4, 5, 6).

Solar irradiation

On a surface level it was anticipated that the days that had the highest solar irradiation would be the days that would, respectively, yield highest water temperature compared to days that had lower solar irradiation. However, from the experiments it was observed that there were days with high solar irradiation but did not yield the hottest water temperature than other days with lower solar irradiation. Day 9 was the day that experienced the highest solar irradiation of 501 W/m^2. On the contrary this day did not produce the highest water temperature. If the solar irradiation of day 9 is compared to that of day 2, where day 2 produced the hottest water temperature but with the third-highest solar irradiation of the 10 days. This raised a point of interest as to why and how this came about. Perhaps, looking into other factors that significantly influence the output water temperature or the harvesting of the solar rays would justify this intriguing behaviour that was observed.

Outdoor temperature

It was observed that this parameter also had significant impact on the water temperature output. When day 9 is comparatively discussed with day 1 it was observed that on day 9 which had the highest solar irradiation (of 501 W/m^2) but had the lowest outdoor temperature (of 15.5 °C), compared to day 1 which had the third-lowest solar irradiation of (370 W/m^2) but the highest outdoor temperature of (of 25.8 °C). Day 9 and day 1 yield the peak water temperatures of 53.5 °C and 58 °C, respectively. Therefore, after highlighting this is can deduced that the outdoor temperature does have an impact of the output temperature when harvesting solar rays via an Evacuated Tube Collector (ETC) unit for the use of solar heating water. Additional to the outdoor temperature analysis, when day 6's parameters (solar irradiation was 457 W/m^2 and outdoor temperature is 19.1 °C) are compared to the of day 9 (solar irradiation was 501 W/m^2 and outdoor temperature is 15.5 °C). Day 6 again yields 64 °C peck water temperature, while day 9 yield 53.4 °C. It is worthwhile to also analyse the wind velocity's impact on the water temperature out when using the ETC unit.

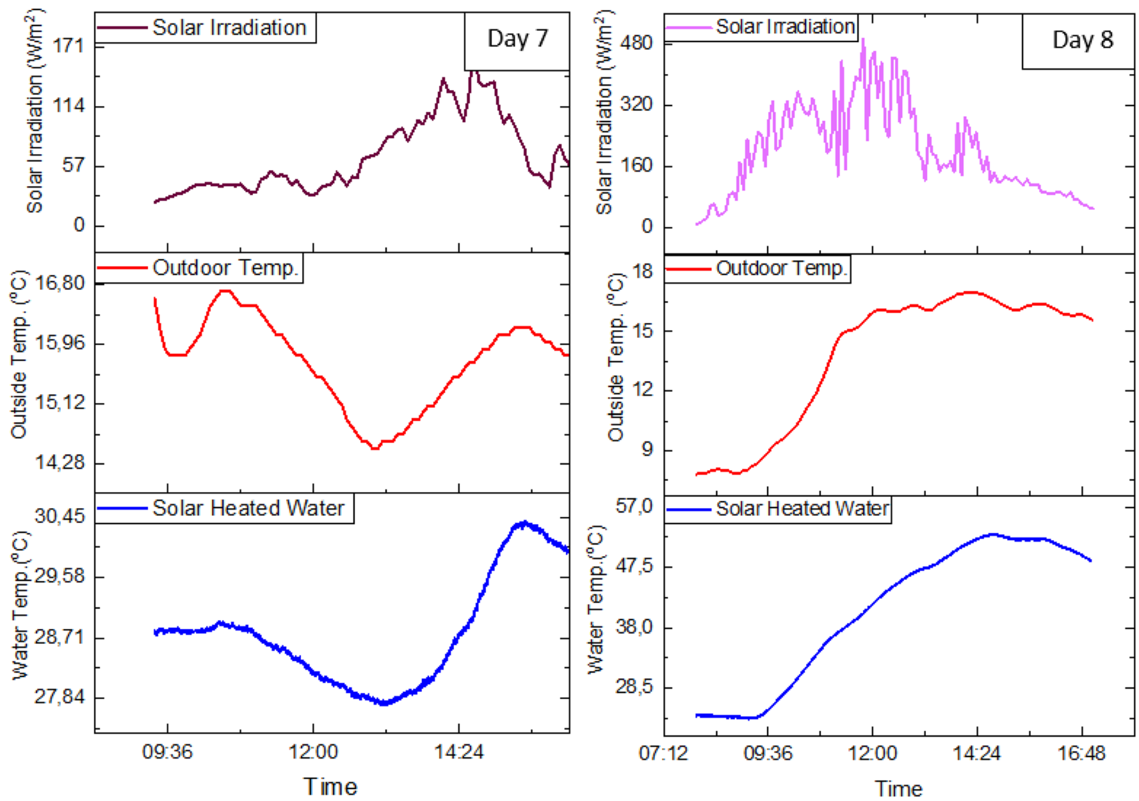

Fig. 7 Solar irradiation, outdoor temperature and solar heated water temperature for day 7 and day 8

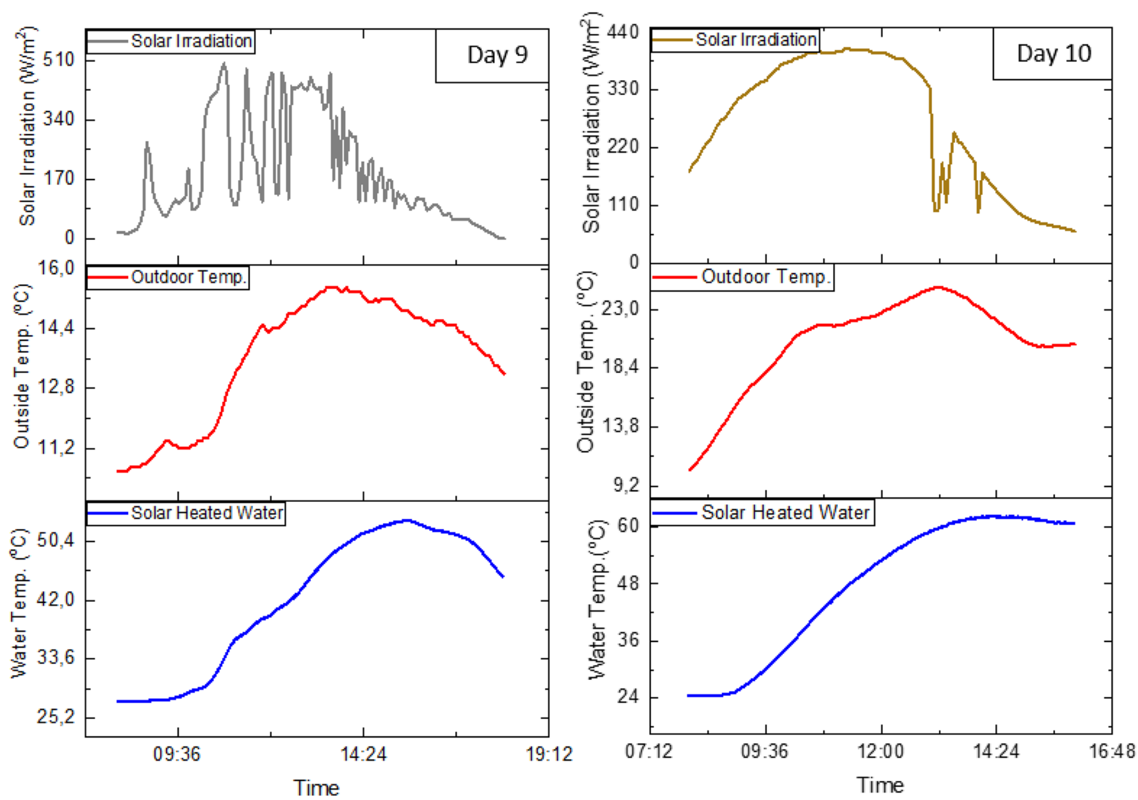

Fig. 8 Solar irradiation, outdoor temperature and solar heated water temperature for day 9 and day 10

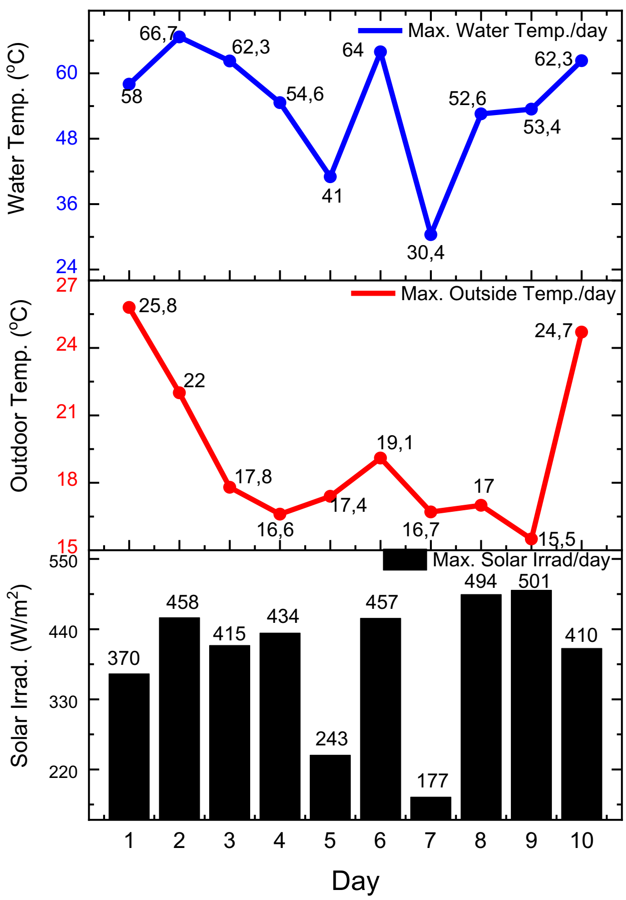

Fig. 9 Summarized results of solar irradiation, outdoor temperature and solar heated water temperature for the mid-winter days

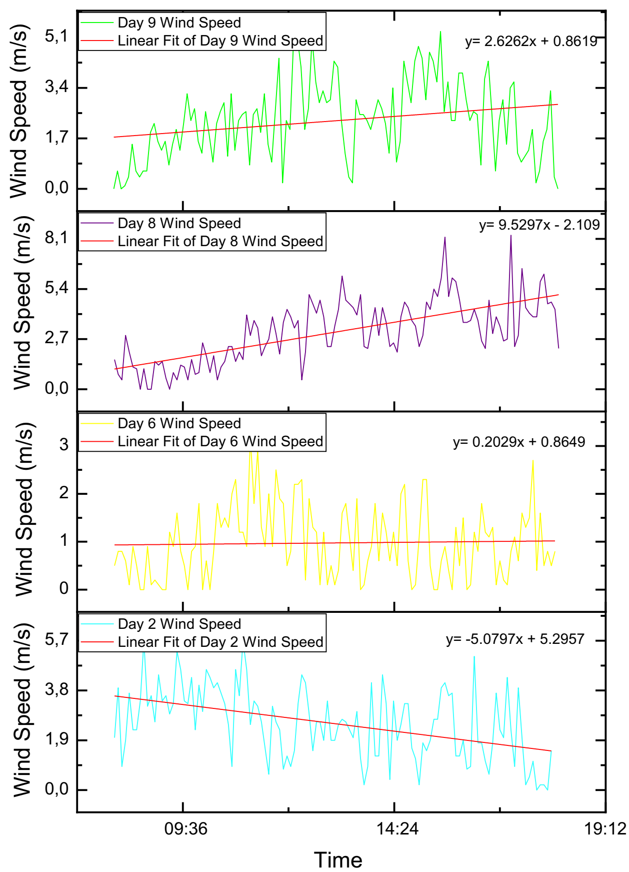

Fig. 10 Wind velocity of day 2, 6, 8 and 9

Wind velocity

Observations showed that the wind velocity had an impact on solar rays harvesting. A graphical presentation of day 2, day 6, day 8 and day 9 (Fig. 10) were scrutinized, since they were the days with the highest water temperatures of the 10 days. If day 8 and day 6 are observed closely in comparison, day 8 has a solar irradiation of 494 W/m^2 and day 6 has 457 W/m^2 (in Figs. 7 and 6). The peak water temperature reached on the two days are 52.8 °C and 64 °C, respectively. However, from this one would anticipate higher water temperature output on days, where there is higher solar irradiation. Another environmental condition parameter was scrutinized to analyse what was influencing the distorted behaviour. It was observed that on day 8 the wind velocity was higher than that of day 6 by more than 4 folds, observed in Fig. 10. Day 8 experienced high wind velocity that gradually increased throughout the day especially at the peak of the solar irradiation of that day. Therefore, this distorted behaviour observed in day 8 is said to be an influence of the wind velocity, if the outdoor temperature is ignored, since the temperature difference between 2 days is 2.1 °C.

It is worth it to independently scrutinize why day 9 failed to yield the highest peak water temperature, whereas it was the day that was observed to have the highest solar irradiation. From the graphical presentation of day 9 on the solar irradiation axes (in Fig. 8) it shows that throughput 9 day there were clouds hindering the solar rays to be harvested freely, this is depicted from the valleys or spiking graph behaviour observed. In addition, the wind velocity was 1 m/s on average throughout the day (Fig. 10). This wind velocity was too slow to influence the harvesting of solar rays (Fig. 9). Below are a graphically presented behaviours of the wind velocity observed for the four days that had the highest solar irradiation (Fig. 10).

Comparative observation between day 3 and day 10, was done. On these day's different performances of wind velocity, outdoor temperature, outdoor humidity, and solar irradiation was observed. However, for the two days the same peak water temperature, was reached when the same water flowrate was maintained through the storage geyser and the evacuated tube unit.

Conclusion

The study undertaken demonstrated various water temperature output when the water velocity circulating through the geyser and ETC manifold were kept constant. In addition, the water quantity (50L) that was stored in the geyser was kept constant, no additional insulation was added to the piping network system, angle of elevation of the tubes and the number of evacuated tubes. Only the environmental conditions were naturally varying on each day. The study undertaken the following were observed that the following:

1. It was also, observed that when using an evacuated tubes not only solar irradiation is a significant input that affects the water temperature output.
2. In this study it was also observed and validated that the wind velocity also has an impact on the output of solar water heating when using an evacuated tube collector unite.
3. It was observed that in mid-winter on Bellville when the outdoor temperature and solar irradiation was, respectively, 22 °C and 458 W/m^2, the ETC unit with 20 tubes can yield a peak water temperature of 66.7 °C when the wind velocity was 3.8 m/s at most throughout the day.
4. This study validates that the environmental factors does impact the output of an ETC unit. This agrees with the studies conducted by various researchers such as that of Sharma et al., (2022).
5. Finally, it is observed that the environmental parameters cannot be individually observed while competently isolating one from the other. Zubriski and Dick (2012) conducted a similar study on 32 tubes ETC unit in different seasons for winter they found that even though the solar irradiation was the lowest by manipulating the angle of tilt one can get optimal performance from the ETC unit, which validates that environmental input parameters has to be collectively analysed to get a better understanding on the performance of the ETC unit.

Recommendations

For future works the following recommendations are suggested to improve on this study:

a) Testing the evacuated tubes collector array at varied angles, to see the different angles of incident how they affect the solar harvesting and water temperature output.
b) Varying the tube quantity on the panel to analyse the impact of varied array size.
c) Formulation a guide suitable to size an evacuated tube collector unite based on South Africa.
d) A critical analytical study advised to quantify each environmental parameter impacts on the water temperature output, when the ETC is used for solar water heating.

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Author contributions
ZM: first draft write up; VM: editing final draft and supervision; ON: editing final draft and supervision. All authors read and approved the final manuscript.

Authors' information
Z. Mdletshe: MEng, DEng Candidate; V. Msom: DEng, Senior Lecturer; O. Nemraoui: PhD, Senior Lecturer.

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Availability of data and materials
The data are available on request through authors from the CPUT repository.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
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References

Abu Mallouh, M., AbdelMeguid, H., & Salah, H. (2022). A comparison and control for different solar water heating system configurations. *Engineering Science and Technology, an International Journal, 35*, 101210. https://doi.org/10.1016/j.jestch.2022.101210

Araya, R., Bustos, F., Contreras, J., & Fuentes, A. (2017). Life-cycle savings for a flat-plate solar water collector plant in Chile. *Renewable Energy, 112*, 365–377. https://doi.org/10.1016/j.renene.2017.05.036

Arif, M. N., Waqas, A., Butt, F. A., Mahmood, M., Khoja, A. H., Ali, M., Ullah, K., Mujtaba, K. M., & Kalam, M. A. (2022). Techno-economic assessment of solar water heating systems for sustainable tourism in northern Pakistan. *Alexandria Engineering Journal, 61*(7), 5485–5499. https://doi.org/10.1016/j.aej.2021.11.006

Chow, T., Dong, Z., Chan, L., Fong, K., & Bai, Y. (2011). Performance evaluation of evacuated tube solar domestic hot water systems in Hong Kong. *Energy and Buildings, 43*(12), 3467–3474. https://doi.org/10.1016/j.enbuild.2011.09.009

Gaonwe, T. P., Kusakana, K., & Hohne, P. A. (2022). A review of solar and air-source renewable water heating systems, under the energy management scheme. *Energy Reports, 8*(15), 1–10. https://doi.org/10.1016/j.egyr.2022.10.065

Guo, F., & Yang, X. (2021). Long-term performance simulation and sensitivity analysis of a large-scale seasonal borehole thermal energy storage

system for industrial waste heat and solar energy. *Energy and Buildings, 236*, 110768. https://doi.org/10.1016/j.enbuild.2021.110768
Hayek, M., Assaf, J., & Lteif, W. (2011). Experimental investigation of the performance of evacuated-tube solar collectors under eastern mediterranean climatic conditions. *Energy Procedia, 6*, 618–626. https://doi.org/10.1016/j.egypro.2011.05.071
Kılkış, Ş., Krajačić, G., Duić, N., Montorsi, L., Wang, Q., Rosen, M. A., & Al-Nimr, M. A. (2019). Research frontiers in sustainable development of energy, water and environment systems in a time of climate crisis. *Energy Conversion and Management, 199*, 111938. https://doi.org/10.1016/j.enconman.2019.111938
Kushwah, A., Kumar, A., Pal, A., & Gaur, M. K. (2021). Experimental analysis and thermal performance of evacuated tube solar collector assisted solar dryer. *Materials Today: Proceedings, 47*(17), 5846–5851. https://doi.org/10.1016/j.matpr.2021.04.243
Kyekyere, E., Ndiritu, H., Hawi, M., & Mwambe, P. (2021). Performance of water in glass evacuated tube solar water heater under kenya climatic condition. *Computational Water, Energy, and Environmental Engineering, 10*(02), 108367.
Lamosa, R. A., Motovoy, I., Khliiev, N., Nikulin, A., Khliyeva, O., Moita, A. S., Krupanek, J., Grosu, Y., Zhelezny, V., Moreira, A. L., & del Barrio Elena, P. (2021). Tetralin + fullerene C60 solutions for thermal management of flat-plate photovoltaic/thermal collector. *Energy Conversion and Management, 248*, 114799. https://doi.org/10.1016/j.enconman.2021.114799
Long, J., Xia, K., Zhong, H., Lu, H., & Yongga, A. (2021). Study on energy-saving operation of a combined heating system of solar hot water and air source heat pump. *Energy Conversion and Management., 229*, 113624. https://doi.org/10.1016/j.enconman.2020.113624
Maraj, A., Londo, A., Gebremedhin, A., & Firat, C. (2019). Energy performance analysis of a forced circulation solar water heating system equipped with a heat pipe evacuated tube collector under the Mediterranean climate conditions. *Renewable Energy, 140*, 874–883. https://doi.org/10.1016/j.renene.2019.03.109
Martin-Escudero, K., Salazar-Herran, K. E., Campos-Celador, A., Diarce-Belloso, G., & Gomez-Arriaran, I. (2019). Solar energy system for heating and domestic hot water supply by means of a heat pump coupled to a photovoltaic ventilated façade. *Solar Energy, 183*, 453–462. https://doi.org/10.1016/j.solener.2019.03.058
Naji, H., & Al-Joboory, S. (2019). Comparative experimental investigation of two evacuated tube solar water heaters of different configurations for domestic application of Baghdad-Iraq. *Energy and Buildings, 203*, 109437. https://doi.org/10.1016/j.enbuild.2019.109437
Pathak, S. K., Tyagi, V. V., Chopra, K., & Sharma, R. K. (2022). Recent development in thermal performance of solar water heating (SWH) systems. *Materials Today: Proceedings, 63*, 778–785. https://doi.org/10.1016/j.matpr.2022.05.502
Sanguinetti, A., Outcault, S., Alston-Stepnitz, E., Moezzi, M., & Ingle, A. (2021). Residential solar water heating: California adopters and their experiences. *Renewable Energy, 170*, 1081–1095. https://doi.org/10.1016/j.renene.2021.02.031
Sharma, D. K., Sharma, D., & Ali, A. H. H. (2022). Energy, exergy, environmental impact, and economic analyses of evacuated tube compound parabolic concentrator–powered solar thermal domestic water heating system. *Environmental Science and Pollution Research, 29*, 82390–82410. https://doi.org/10.1007/s11356-022-21505-2
Singh, S., Gill, R. S., Hans, V. S., & Mittal, T. C. (2022). Experimental performance and economic viability of evacuated tube solar collector assisted greenhouse dryer for sustainable development. *Energy, 241*, 122794. https://doi.org/10.1016/j.energy.2021.122794
Siuta-Olcha, A., Cholewa, T., & Dopieralska-Howoruszko, K. (2021). Experimental studies of thermal performance of an evacuated tube heat pipe solar collector in Polish climatic conditions. *Environmental Science and Pollution Research, 28*, 14319–14328. https://doi.org/10.1007/s11356-020-07920-3
Tabarhoseini, S. M., Sheikholeslami, M., & Said, Z. (2022). Recent advances on the evacuated tube solar collector scrutinizing latest innovations in thermal performance improvement involving economic and environmental analysis. *Solar Energy Materials and Solar Cells, 241*, 111733. https://doi.org/10.1016/j.solmat.2022.111733
Weaver, R., Lim, C., & Sobhansarbandi, S. L. S. (2022). Thermal performance improvement of energy storage materials for low operating temperature solar water heating systems". *Sustainable Energy Technologies and Assessments, 52*, 102298. https://doi.org/10.1016/j.seta.2022.102298
Yanhua, L., Wengang, H., Hongwen, Y., Jian, Z., & Mingxin, L. (2019). Performance and economic evaluation of evacuated tube solar collector with auxiliary electric heater for rural heating. *Energy Procedia, 158*, 186–191. https://doi.org/10.1016/j.egypro.2019.01.068
Zubriski, S. E., & Dick, K. J. (2012). Measurement of the efficiency of evacuated tube solar collectors under various operating conditions. *Journal of Green Building., 7*(3), 114–130.

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