International Journal of Sustainable Energy and Environmental Research
2023 Vol. 12, No. 1, pp. 10-16
ISSN(e): 2306-6253
ISSN(p): 2312-5764
DOI: 10.18488/13.v12i1.3379

Weather influence on the performance of solar collector

Hakizabera Olivier[1+]
Uwayezu Emmanuel[2]
Hirwa Gloria[3]

[1]*Rwanda Polytechnic (Integrated Polytechnic Regional Center Kigali), Rwanda.*
Email: hajeannol544@gmail.com
[2]*College of Mechanical and Vehicle Engineering, Taiyuan University of Technology, China.*
Email: kyrieguy11@gmail.com
[3]*School of Architecture and Design, Beijing Jiaotong University, China.*
Email: gloriahirwa2019@yahoo.com

(+ Corresponding author)

Article History
Received: 28 February 2023
Revised: 8 May 2023
Accepted: 17 May 2023
Published: 25 May 2023

Keywords
Environmental weather factors
Evacuated tube solar collector
Heat
Linear model regression analysis
Solar radiation
Temperature
Winter season.

ABSTRACT

A laboratory-scale evacuated tube solar collector (ETSCs) has been developed and tested for unloading conditions in Lanzhou, China. clear sky and cloudy conditions have been tested. Heat is generally considered instantaneous because it is a function of multiple instantaneous factors, like ambient temperature and solar radiation. The results show a clear sky day with a maximum and average value of ambient temperature, outlet, inlet, and solar radiation of 12 and -6⁰C, 56 and 31⁰C, 69 and 34⁰C, 931 and 576W/m², respectively, while a cloudy day was eight and -3⁰C and 861.2 and 449W/m² respectively. Clear sky day maximum and the average mass flow rate was 0.25 and 0.21 Kg/sec, while the cloudy flow rate was 0.27 and 0.03 Kg/sec, respectively. A clear sky has a heat loss of -0.307 and -0.05kW for a cloudy day. R square were 0.76 and 0.4 for clear sky and cloudy day, respectively. For the heat and radiation correlation relationship, a clear sky has a slope of 0.0029 and 0.0539 for a cloudy day. In other conditions, the solar radiation per unit area increases by 1 W/m², and the daily heat is collected. Increasing A W/m², the temperature difference between the average temperature of the hot water storage tank and the average temperature of the environment increases by one °C, and the daily heat collection decreases A W/m². It concludes that a clear sky has much better efficiency than a cloudy day.

Contribution/Originality: The main objective of this research is to examine ETSC (Evacuated Tube Solar Collector) thermal performance in extreme weather conditions. The effects of weather conditions like ambient temperature, solar radiation, and local climatic conditions on the system's long-term performance are investigated. The heat loss gain and loss in times of Solar radiation and reduced temperature of solar collectors on the performance parameters of these solar collectors will be theoretically and experimentally determined.

1. INTRODUCTION

Solar water heating collector systems (SWHs) are the most alternative energy systems for heating because of their environmental protection and fuel reduction (Ko, 2015). Depending on whether conditions require running or not the pump (Wang, Yang, Qiu, Zhang, & Zhao, 2015). Conventional Flat plate collector systems (FPCs) were discovered for use in clear skies and hot climates. Their benefits become unfavorable during cold and cloudy days. Condensation and moisture can also destroy the performance and eventual system failure. The first advantage of ETCs is that too reduce convection and conduction losses (Kalogirou, 2004) they can even perform even in cold weather when FPCs perform badly due to heat losses (Alghoul, Sulaiman, Azmi, & Wahab, 2005). There has recently been a significant expansion of the ETC market of ETCs in China, Europe, and Japan due to the globally growing industries for ETCs (Sabiha, Saidur, Mekhilef, & Mahian, 2015). Such as the recent work of Mazarrón, Porras-Prieto, García, and Benavente (2016) this growth has led to more studies analyzing solar collector thermal performance under specific consumption patterns. Ayompe, Duffy, Mc Keever, Conlon, and McCormack (2011) investigated a two-phase thermosyphon SWH. the best efficiency system was 82%, which is higher than the conventional SWH. The thermal resistance-capacitor method is used as a theoretical model. The simulation predictions have the same value as the experimental data within an average error deviation of ±6%. SWHs (FPC, ETC) sustainability life cycle environment in regions with low solar irradiation, such as the United Kingdom, was developed by simulation. The main conclusion was that solar thermal systems do not represent a more environmentally sustainable alternative to fossil fuel-based water heating (Mutombo & Numbi, 2022). Dust effect on the performance of the solar collector was analyzed in Hakizabera, Li, Yang, and Heli (2018). The results show that the daily optical efficiency decreased by 17.6 %, and the average stagnation temperature decreased from 7.3–1.8^{0}C in a solar collector with 2.610-05 mg/m^2. Linear regression analysis (Ibrahim et al., 2012) investigates the relationship between Temperature and solar radiation in Perlis, Northern Malaysia. The linear correlation coefficient value was 0.7473, and about 56% of the variability in temperature was calculated by the straight line as tit the solar radiation plot. The target objective of this research is to examine ETC thermal performance in extreme weather conditions. An experimental test unit was set up at Minquin County (China) to record the thermal performance of ETC. The numerical technique is adapted to correlate measurements to collector Heat. The long-term performance of water-in-glass solar water heaters is evaluated Theoretically and experimentally. The effects of weather conditions like ambient temperature, solar radiation, and local climatic conditions on the system's long-term performance are investigated. The current research investigates Control heat loss gain and loss in times of Solar radiation and reduced temperature of solar collectors. Their effect on the performance parameters of these solar collectors will be discussed and determined.

2. LOCATION AND METEOROLOGICAL DATA

An experimental set-up was installed and experimentally investigated at Minquin County (latitude 38^{0}34'N, Longitude 103^{0}3'E), China. Figure 1 shows a water-in glass collector made of 30 evacuated tubes and a storage tank. The typical control system has four heat coils with platinum resistance temperature sensors on the ambient, inlet, outlet, and collector tank. The mass-flow rate of hot water was recorded by LWGY-15 (Turbine Flow Meter). A Pyranometer recorded the total solar radiation. Each measuring instrument was connected to the computer via interfaces, and Agilent 349702 was recorded every 10 s intervals. Meteorological data were processed by spline interpolation with a time step of every 10 seconds.

Figure 1. EVT experimentally set up.

The performance of experiments was conducted on a whole Clear sky and Cloudy day. The results presented in Figure 2 and 3 show a clear sky day with a maximum and average value of the ambient temperature of 12 and -6^{0}C while Solar radiation was 931 and 576W/m^2, respectively. The cloudy day was eight and -3^{0}C and 861.2 and 449W/m^2, respectively. Figure 4 and 5 show clear sky on/ off solar control collector, inlet, and outlet temperature and their mass flow rate. The maximum and average outlet inlet was 56 and 31^{0}C, 69 and 34^{0C}, while the flow rate was 0.25 and 0.21 Kg/sec. The cloudy day was 57 and 27^{0}C, 52 and 32^{0}C, while the flow rate was 0.27 and 0.03 Kg/sec, respectively. Data collection is summarized in Table 1 and 2.

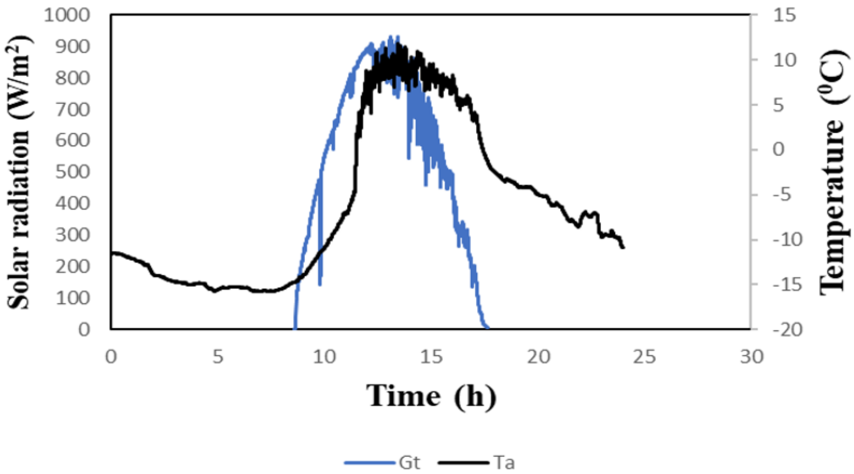

Figure 2. Clear sky ambient temperature and solar radiation.

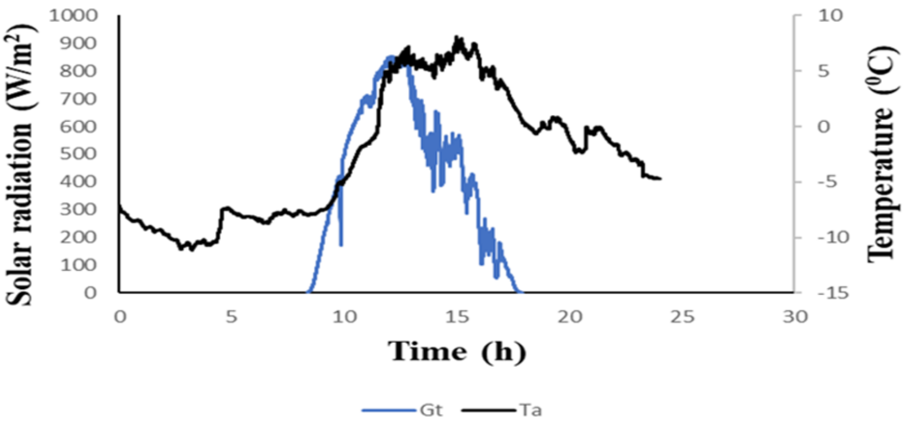

Figure 3. Cloudy ambient temperature and solar radiation.

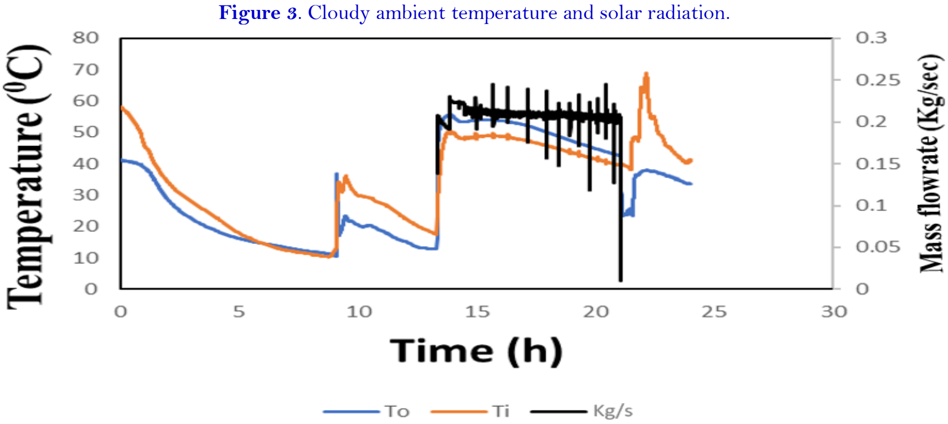

Figure 4. Clear sky on/off pump control.

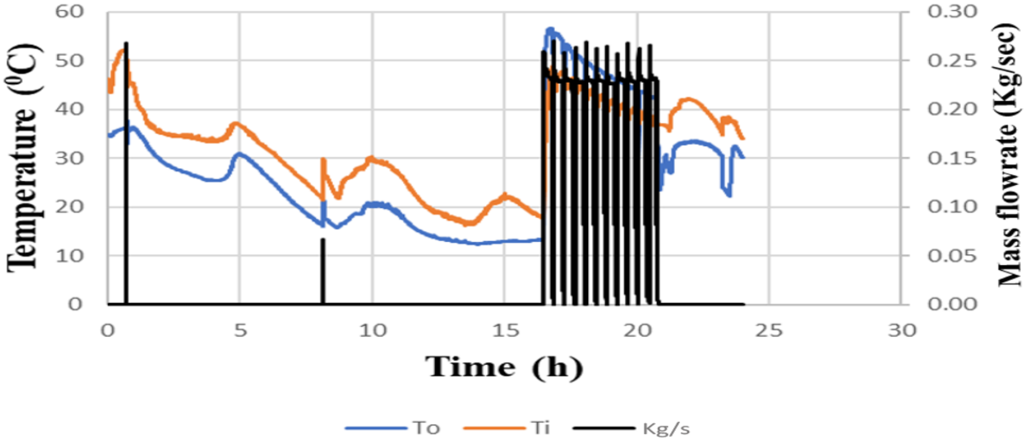

Figure 5. Cloudy sky on/off pump control.

Table 1. Data collection clear sky.

	G_T (W/m²)	Ta (°C)	To (°C)	Ti (°C)	M(Kg/s)
Maximum	931	12	56	69	0.25
Average	576	-6	31	34	0.21

Table 2. Data collection cloudy day.

	G_T (W/m²)	Ta (°C)	To (°C)	Ti (°C)	M(Kg/s)
Maximum	861	8	57	52	0.27
Average	449	-3	27	32	0.03

3. THEORETICAL ANALYSIS

The heat rate gained by the fluid is then given by:

$$Q= mCp(T_o - T_i) \quad (1)$$

Where: Q is the heat delivered to the tank (kW), m is the mass flow rate of the fluid (kg/sec), Cp is the specific heat capacity of the collector (J/kg/°C), To and Ti is the outlet and inlet temperature of the heat-transfer fluid (°C).The net power output Equation 1 can be written as Ayompe et al. (2011):

$$Q = A_c F_R [G_T - U_L (T_o - T_i)] \quad (2)$$

Where F_R is the heat removal factor, and U_L is the heat loss coefficient. Ta is the ambient temperature, and Ac is the area of the ETSC (m²).

4. RESULT AND DISCUSSION

After recording all data points on a range of operating conditions. Multi-linear regression techniques were used to determine the collector's heat curve. Daily Heat experimental results are presented in graphs and equations that describe the collector heat against a reduced temperature (Ti-Ta) and Solar Radiation (G_T). The data were analyzed to obtain a simple relation between heat gain (y) and ambient-inlet temperature difference (x). Equation 2 became a first-degree function of:

$$y = ax + b \quad (3)$$

The constants A and B were evaluated either experimentally or analytically. We make a scatter plot for a clear sky, as shown in Figure 6 shows an average of Heat equal to 4kW. The estimation of parameters in the regression model is calculated using the least squares method as given in Equation 3. The value of A and B is -0.307 and 17.5, respectively. The least squares that fit the net power data are y = -0.307x + 17.5, where y is the heat corresponding to the temperature differences of x cases. The variance is R^2 = 0.766 (about 76%) of the temperature accounted for the straight-line fit to Heat.

For a cloudy day, Figure 7 shows an average of Heat equal to 5kW. The least squares fit the net power data is y = -0.8083x + 38.576, where y is the solar radiation corresponding to the air temperature of x cases. R^2 = 0.4024 (about 40%) of the temperature accounted for the straight-line fit to solar radiation.

Figure 8 and Figure 9 show clear sky and cloudy day relation analysis between heat gain (y) and solar radiation (x). The regression fit to the net power data is y = 0.0029x + 3.4194 and y = 0.0539x + 2.9796. The variance of R^2 = 0.1981 and 0.4094, respectively. The characteristics analysis of this solar collector is summarized in Table 3 and 4.

Table 1. Main parameters of regression adjustment for Q and (Ti-Ta).

Days	R square	A	B (kW)	Average net power (kW)
Clear sky	0.766	-0.307	17.501	17
Cloudy	0.4024	-0.8083	38.576	4

Table 2. Main parameters of regression adjustment for Q and G_T.

Days	R square	A	B(kW)	Average net power (kW)
Clear sky	0.1981	0.0029	3.4194	29
Cloudy	0.4094	0.0539	2.9796	5

R Square will Indicate the total variation in the average collection of Heat of solar water heaters, B is the intercept point of Heat, and A is the Total Heat Loss.

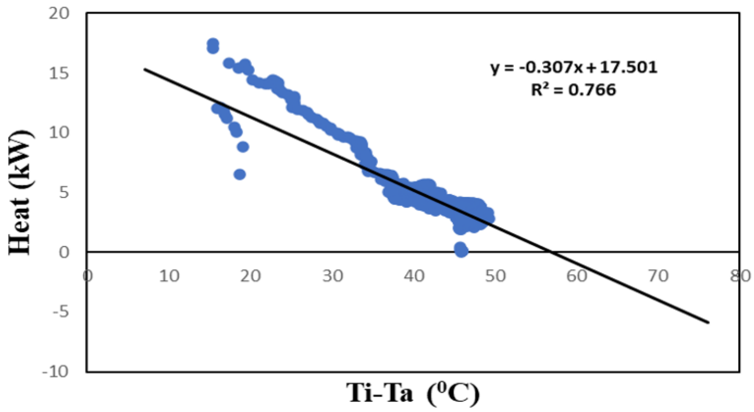

Figure 6. Heat versus temperature difference for a clear sky.

As the hours pass, the energy transferred to the tank increases. The accumulated energy increases linearly with irradiation, which is most evident later in the day (Figure 8 and Figure 9).

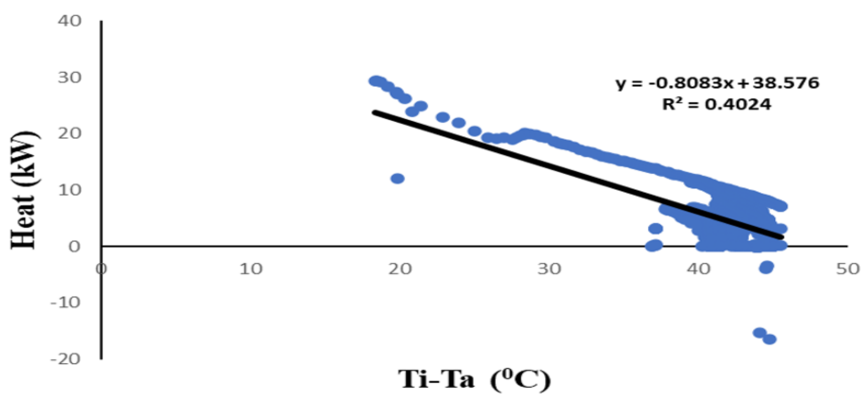

Figure 7. Heat versus temperature difference for a cloudy day.

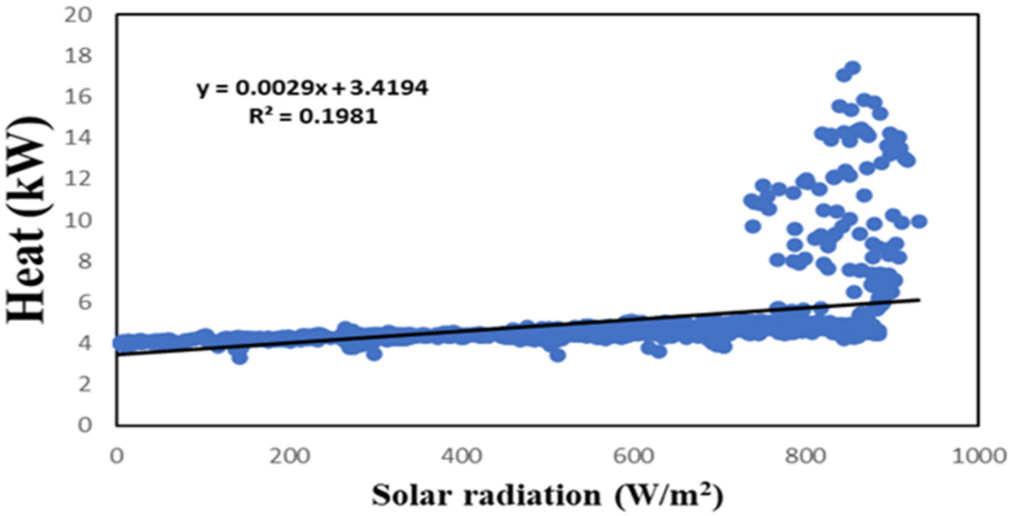

Figure 8. Heat versus solar radiation for a clear sky.

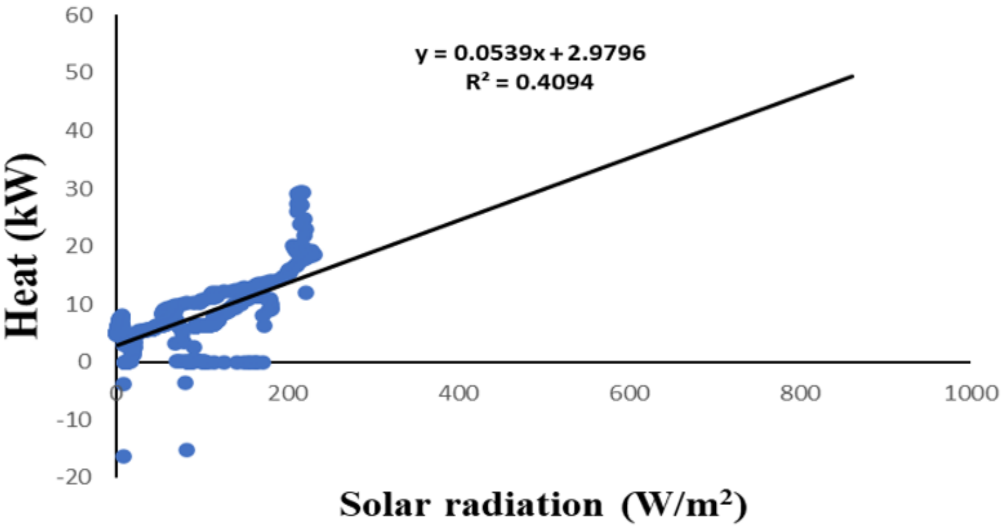

Figure 9. Heat versus solar radiation for a cloudy day.

5. CONCLUSION

Test requirements include temperature, solar radiation, outdoor environment, the mass flow of water entering the collector, the specific heat of water, inlet, and outlet water temperature, and hourly to daily. All these parameters will refer to control the influence of weather on the evacuated Tube Solar Collectors. The result above shows how to use regression analysis to estimate solar radiation in Lanzhou, China. The experiments were conducted to characterize the performance of ETC. The performance of experiments was conducted on a whole Clear sky and Cloudy day.

The results show a clear sky day with a maximum and average value of the ambient temperature of 12 and -6⁰C while Solar radiation was 931 and 576W/m^2, respectively. The cloudy day was eight and -3⁰C and 861.2 and 449W/m^2, respectively. Other results show clear sky on/ off solar control collector the inlet and outlet temperature with their mass flow rate. The maximum and average outlet and inlet temperatures were 56 and 31⁰C, 69 and 34⁰C, while the flow rate was 0.25 and 0.21 Kg/sec. The cloudy day was 57 and 27⁰C, 52 and 32⁰C, while the flow rate was 0.27 and 0.03 Kg/sec, respectively. The collector heat Q is plotted against (Ti – Ta)/I and solar radiation G_T. The slope of this line (- F_R U_L or A) represents the collector's heat loss rate. The heat and temperature difference relationship result shows that the clear sky and cloudy day have a slope of -0.307 and -0.05, respectively. For the heat and radiation relationship, a clear sky has a slope of 0.0029 and 0.0539 for a cloudy day. Experimental result reveals a slight increase in the heat in cloudy weather conditions compared to clear sky conditions due to low ambient temperature.

The solar radiation per unit area increases by 1 W/m^2, and the daily heat is collected. Increasing A W/m^2, the temperature difference between the average temperature of the hot water storage tank and the average temperature of the environment increases by one °C, and the daily heat collection decreases A W/m2. The results show that for other conditions, the solar radiation per unit area increases by 1 W/m2, and the daily heat is collected. Increasing the unit of A W/m2, the temperature difference between the average temperature of the hot water storage tank and the average temperature of the environment increases by 1 °C, and the daily heat collection decreases A W/m2. It concludes that a clear sky has less heat loss than a cloudy day and a clear sky R2 is higher than a cloud day. The main conclusion is that a clear sky has much better efficiency than a cloudy day.

Funding: This study received no specific financial support.
Competing Interests: The authors declare that they have no competing interests.
Authors' Contributions: All authors contributed equally to the conception and design of the study.

REFERENCES

Alghoul, M., Sulaiman, M., Azmi, B., & Wahab, M. A. (2005). Review of materials for solar thermal collectors. *Anti-Corrosion Methods and Materials*, *52*(4), 199-206. http://dx.doi.org/10.1108/00035590510603210

Ayompe, L., Duffy, A., Mc Keever, M., Conlon, M., & McCormack, S. (2011). Comparative field performance study of flat plate and heat pipe evacuated tube collectors (ETCs) for domestic water heating systems in a temperate climate. *Energy*, *36*(5), 3370-3378. https://doi.org/10.1016/j.energy.2011.03.034

Hakizabera, O., Li, J., Yang, J., & Heli, Y. (2018). Dust effect on evacuated tube solar collector in Minquin, China. *International Journal of Energy and Environmental Research*, *6*(2), 1-11.

Ibrahim, S., Daut, I., Irwan, Y., Irwanto, M., Gomesh, N., & Farhana, Z. (2012). Linear regression model in estimating solar radiation in Perlis. *Energy Procedia*, *18*, 1402-1412. https://doi.org/10.1016/j.egypro.2012.05.156

Kalogirou, S. A. (2004). Solar thermal collectors and applications. *Progress in Energy and Combustion Science*, *30*, 231–295. http://dx.doi.org/10.1016/j.pecs.2004.02.001

Ko, M. J. (2015). A novel design method for optimizing an indirect forced circulation solar water heating system based on life cycle cost using a genetic algorithm. *Energies*, *8*(10), 11592-11617. https://doi.org/10.3390/en81011592

Mazarrón, F. R., Porras-Prieto, C. J., García, J. L., & Benavente, R. M. (2016). Feasibility of active solar water heating systems with evacuated tube collector at different operational water temperatures. *Energy Conversion and Management*, *113*, 16-26. https://doi.org/10.1016/j.enconman.2016.01.046

Mutombo, N. M.-A., & Numbi, B. P. (2022). Development of a linear regression model based on the most influential predictors for a research office cooling load. *Energies*, *15*(14), 5097. https://doi.org/10.3390/en15145097

Sabiha, M., Saidur, R., Mekhilef, S., & Mahian, O. (2015). Progress and latest developments of evacuated tube solar collectors. *Renewable and Sustainable Energy Reviews*, *51*, 1038-1054. https://doi.org/10.1016/j.rser.2015.07.016

Wang, Z., Yang, W., Qiu, F., Zhang, X., & Zhao, X. (2015). Solar water heating: From theory, application, marketing and research. *Renewable and Sustainable Energy Reviews*, *41*, 68-84. https://doi.org/10.1016/j.rser.2014.08.026