Integration and Analysis of Heat Exchangers and Refrigeration Units for Outdoor Drinking Water Through Industrial Secondment at Pretoria Portland Cement

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Abstract

The research investigated the effectiveness of Thermoelectric Coolers (TEC) as a viable cooling option for outdoor refrigeration purposes used outdoor activities e.g. sport events, graduations and wedding ceremonies. The model utilized the technology of a TECs which are solid state current devices that operate by applying DC power and transfers heat from cold side to hot side, acting as a heat exchanger. The performances and effectiveness of the unit was studied by determining the maximum cooling time of system, the number of peltier devices and the optimum positioning of the peltiers needed to produce the required refrigeration of a 10L water tank. Solid Works was used to carry out thermal simulations on the designed water cooler in a real time environment at outdoor ambient temperature to observe the effects of the parameters described above. The designed system was able to cool down a water tank of 10L from 30℃ to 10℃ in 20 minutes by using 4 peltiers with a total refrigeration power of 240W by using 280W solar power. Thermostatic control was seen to reduce power consumption of the system by 37.5%. which in turn reduced the size of the solar panel. For maximum efficiency the cold side of the peltiers must be attached to heat sinks with fins for maximum heat removal from the tank.

Keywords
Refrigeration, Thermoelectric cooler (TEC), peltier, thermal conductivity, thermostat.

1 INTRODUCTION

Water as the main contributor to the survival of all people has significantly become the most vital necessity in public gathering such as sports events, weddings and graduations. However, cool drinking water is usually not ready available during these events. Modern water dispensers have been designed to supply only cold drinking water in residential and commercial areas. There are two main types of water coolers which are water coolers without bottles and water coolers with bottles. Bottle-less water coolers are most suitable for outdoor use and are usually connected to a continuous supply of municipal water and electricity and dispense chilled water, which is stored in a small tank after a refrigeration cycle has passed through. The power sources of water cooling devices range from large public dispensers which are electrically powered by AC to portable dispensers which can be battery powered (Pearlson,2019). Figure 1 shows a typical battery powered water cooler.

Figure. 1. Battery powered portable water cooler (Pearlson,2019).

Pretoria Portland Cement (PPC) is one of the companies in Zimbabwe that holds outdoor sport events for its employees and is located in hot regions of the country i.e. Harare and Bulawayo. Figure 2 displays the minimum and the maximum monthly average temperatures in Harare, Zimbabwe during the year 2019. Such high temperatures require the need of cool drinking water during such activities. The solution to the problem can be solved by introducing a self-sustainable system in public places that is able to maintain water at drinkable conditions. Drinking cold water in a hot climate offers the benefits of preventing the body from overheating. This is because the body can maintain a low core temperature by drinking cold water (Yunus A, Cengel M, 2006).

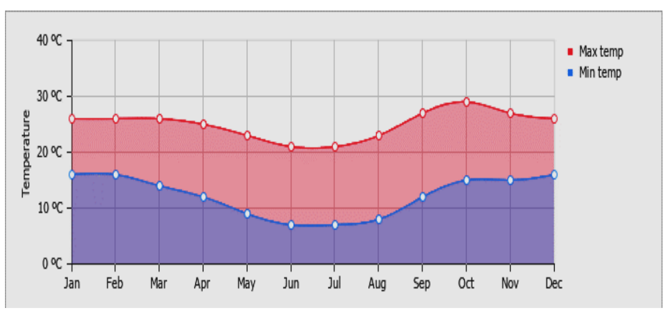

Figure 1: Average minimum and maximum temperature in Harare in Celsius (Pearlson,2019).

The goal of this paper is to develop an outdoor solar powered drinking water refrigeration unit that cools, stores and dispense drinking water. However, the following parameters were tested if the design is able to: cool down the municipal water from warm temperatures which is undrinkable down to 15ºC, withstand outdoor temperatures, be maintained at minimum cost and durability.

2 LITERATURE REVIEW

S.M.A. Rahman et (2018) researched on a portable thermoelectric cooling system which they designed, fabricated and tested based on the principle of thermoelectric module for both cooling and heating application (Rahman S.M.A, 2018). They integrated solar energy to power the thermoelectric module in order to drive the refrigerator as shown in Fig 3.

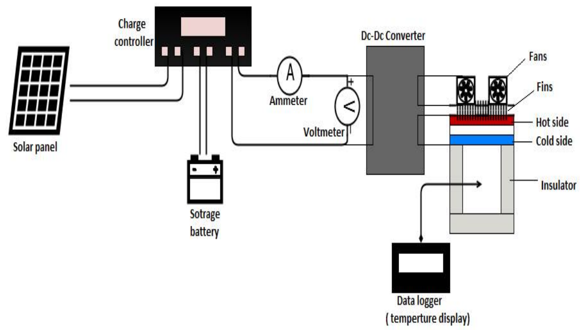

Figure 3: A schematic diagram shows the connection of all main components of the refrigerator (Rahman S.M.A, 2018)

A storage battery was included to run and backup the system in cloudy and rainy conditions. Experimental results revealed that the proposed system achieved and maintained the target temperature inside the cooling chamber during day time as well as at night. Cost analysis demonstrated that such systems can be economically viable when compared to traditional refrigeration. A low coefficient of 0.66 was obtained, which is bit lower compared to conventional refrigerators. The study concluded that the thermoelectric refrigerator is environmentally friendly since it does not produce chlorofluorocarbon (CFC) as in the conventional refrigerators.

R.S. Fayazahame et al (2005) studied development a system which could provide cooling and heating effect simultaneously without moving mechanical parts (Fayazahamed R.S, 2005). The design utilised solid-state devices to cool water without use of refrigerants and hence eliminating emission of CFC. This system resulted in a compact and small in size, weight and price of the water dispenser. This system was less effective for cooling than the conventional water dispenser but improvements were recommended by using copper heat exchangers. The cooling power was seen to increase by using a temperature controller that increases the power efficiency. The system was able to reduce water temperature from 27 degrees to 17 degrees in 30 minutes. Figure 4 shows the setup of the experimental work.

Figure 4: Experimental setup of project (C. Hommalee et al, 2002)

C. Hommalee et al (2002) conducted a project on a cold-hot water dispenser with thermoelectric module system that consisted of a cold-water loop, a hot water loop, a coolant loop, and a thermoelectric module (Sivakumar.N, et al, 2018). The cooling and heating capacities obtained from the cold-hot water dispenser with TMS were compared with those from a conventional cold-hot water dispenser with a compression refrigeration system (CRS). The cold-hot water dispenser with TMS operated at the minimum cold water temperature of 10 to 13°C.

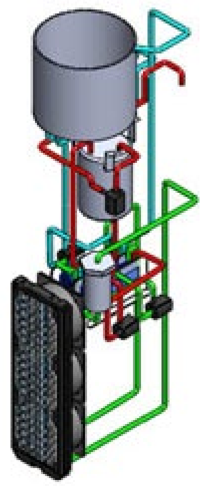

Figure 5: Water dispenser with TMS loops (Sivakumar.N, et al, 2018)

Sivakumar. N et al (2018) conducted a project to provide refrigeration system to the remote areas where power supply is not possible. Their aim was to study the cooling effect on DC as well as AC supply and compare the results coming out and determining the coefficient of performance of the system. The major challenge faced in the thermoelectric cooling was lower COP especially when the capacity of system increases. The minimum temperature achieved was found to be 15°C for cooling.

3 RESULTS

To cool down a certain volume of water from an average temperature of 30°C in summer conditions down to 10°C in a given time of less than 1 hour the following stages are conducted in the design. Heat removed per litre.QR=83 600 J/kg and the Rate of heat removed per kg, $\dot{Q}_r$ in 1hour= 23.2 W.

3.1 Selection of the Thermoelectric Coolers (TEC)

The selection of the TECs (Figure 7) that can pump out heat from the tank of water from 30°C to 10°C in 15 minutes is done based on the standards of TECs available on the commercial market. A **TEC-12706** peltier of 60 Watts rated refrigeration power is selected based on its ability to operate under varying input power conditions which is characterised by PV panel

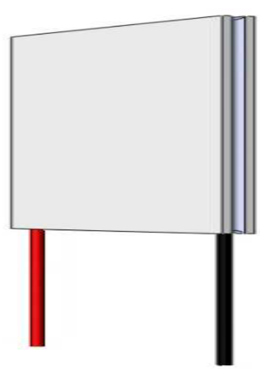

Figure 6: TEC-12706 peltier (Chootichai H, 2007)

3.2 Sizing of cooling tank and TECs

To cool down a certain volume of water from an average temperature of 30°C in summer conditions down to 10°C in a given time of less than 1 hour the following stages are conducted in the design. Heat removed per litre, Q_R=83 600 J/kg. Rate of heat removed per kg, $\dot{Q}_r$ in 1hour= 23.2 W. The number of 60W TEC12706 peltiers (table 1) required to cool 5,10 and 15 litres of water is found by using equation (1):

$$\frac{Rate\ of\ heat\ removal\ \times mass\ of\ water}{Refrigeration\ power\ of\ 1\ TEC} = \frac{\dot{Q}_r \times m}{\dot{Q}_{TEC}} \qquad (1)$$

Table 1. Number of peltiers required for different tank sizes

Volume (L)	Number of peltiers
5	2
10	4
15	6

3.3 Sizing of heat sinks

In the design of the heat sink it should be noted that not only the power rating of the TEC should be considered in the sizing of the heat sink but also the I^2R heating effect of the TEC generated. The heat sink sizing, Q_{HS} would be:

$$Q_{HS} = (Imin \times Vmax) + Qmax \qquad (2)$$

For the selected peltier with I_{MAX} of 4A and V_{MAX} of 15.4V the designed Q_{HS} was =121.6 W.

3.4 Selection of air flow convection

To increase the rate of heat removal from the heat sink for maximum performance of the TECs forced air convection with the aid of a DC fan is chosen over natural air convection flow. This is achieved by attaching the fan Figure 8a at the back of the heat sink Figure 8b.

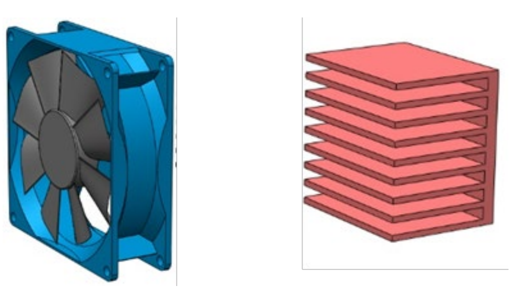

Figure 7: (a) Fan (b) Heat sink

3.5 Transient analysis

SolidWorks was used to simulate the most effective tank size and peltier number combination. The study simulated the refrigeration process over a time period of 15 minutes in 15 seconds intervals. For analysis the average temperature of the simulation results was assumed to be the actual temperature of water in the tank. Based on the results from the three tanks the 15L tank (Figure 10a) disqualify as it cools the water to about 21.5℃ as shown in Figure 10b while the targeted temperature of 15℃. The 10L tank (Figure 9a) is selected over the 5L tank (Figure 8a) as it offers more volume to serve more people with cool despite having the similar temperature range of about 17℃-19℃ as indicated in Figure 8b and 9b.

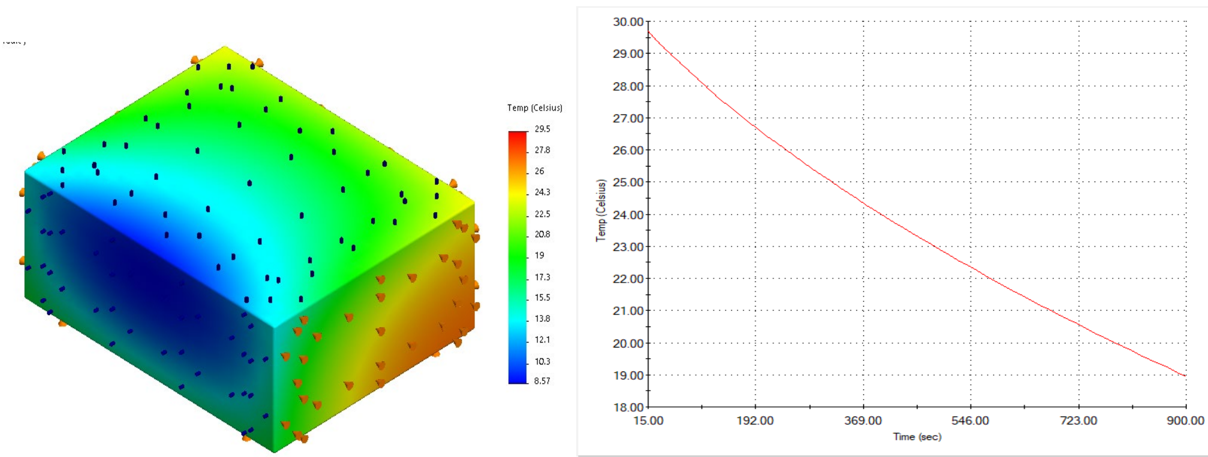

Figure8: (a)Transient analysis of 5L water tank with 2 peltiers (b) Response graph of the refrigeration process

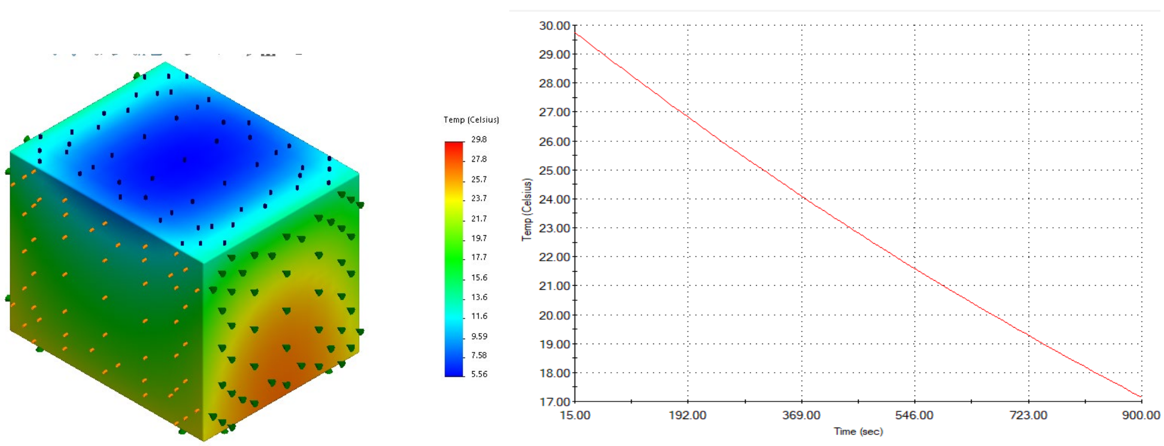

Figure 9: (a)Transient analysis of 10L water tank with 4 peltiers (b) Response graph of the refrigeration process

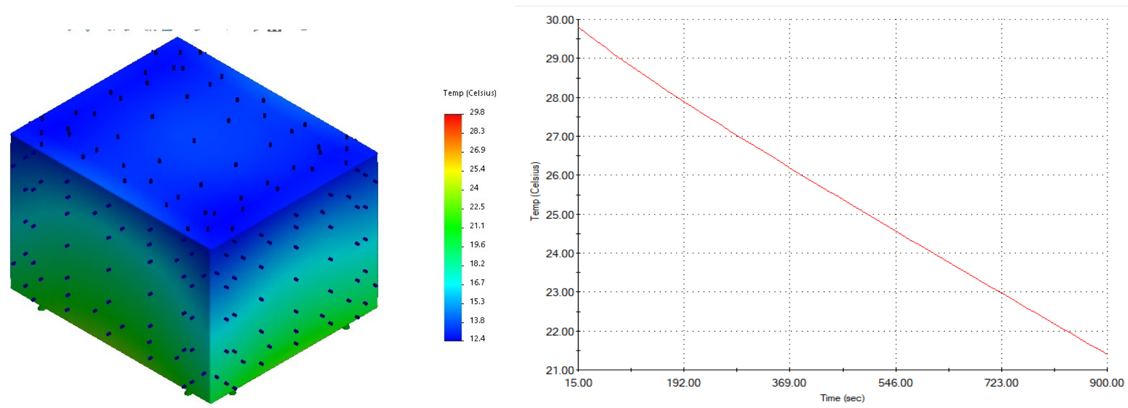

Figure 10: (a)Transient analysis of 15L water tank with 6 peltiers (b) Response graph of the refrigeration process

Further simulations were carried out aimed at determining the optimum positioning of peltier coolers for minimum achievement of temperature in the tank. Figure 9 shows the thermal effects when the 2 peltiers are put at different positions of the tank. From the simulation results Figure 9c was selected as the most optimum position as it covers a greater cooling surface area as compared to the other two positions. However, two additional peltiers were added on opposite sides so as to increase the cooling surface area.

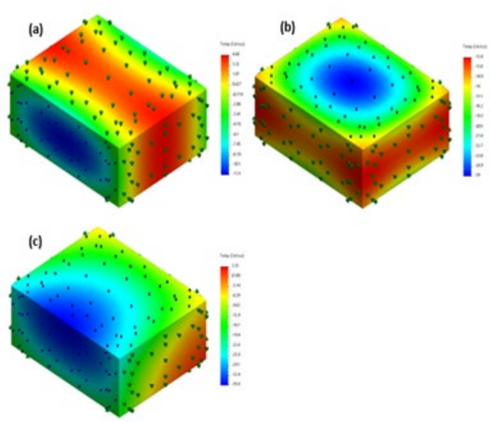

Figure 9: (a) Steady state result for peltiers sideways (b) Steady state result for peltiers top/bottm (c) Steady state result for peltiers top/sid

In line with industry 4.0, the design replaced the convectional material used is old cooling systems such as compressors and electric motors. By considering the optimum number of peltiers, tank size and power required to cool down the water to the required temperature, Figure 10 shows the final design of the outdoor cooling system.

Figure 10: Final CAD model of the design

CONCLUSION AND RECOMMANDATIONS

Based on the simulations carried out by SolidWorks, the designed system was able to cool down a water tank of 10L from 30℃ to 10℃ in 20 minutes by using 4 peltiers with a total refrigeration power of 240W by using 280W solar power. Thermostatic control was seen to reduce power consumption of the system by 37.5%. which in turn reduced the size of the solar panel. For maximum efficiency the cold side of the peltiers must be attached to heat sinks with fins for maximum heat removal from the tank. For maximum heat shield mechanism of the water tank from direct sunlight, the structure must be painted white with at least three or more insulator covers connected thermally in parallel.

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Biography

Roy N Mushonga is a Lecturer in the Faculty of Engineering and Built Environment at the University of Zimbabwe. He attained his Master’s Degree in Applied Design at Isfahan University of Technology (Iran) in 2019 and focused in Solid Mechanics and his Honors Degree in Mechanical Engineering at University of Zimbabwe in 2013. His area of research is Plates and Shells, Metal forming Processes and Finite Element Analyses (FEA). His also into maintenance of different industrial machines and is specialized in automation and PLC programming.

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