Experimental Investigation of Evaporative Hybrid Water Cooler

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ABSTRACT

The water cooler is a device which cools and dispenses water which is used to provide easy access to drinking water. The water coolers which are currently available in the market are works on the concept of VCR (Vapour Compression Refrigeration) System. These water coolers consume high electric power almost 250-350W, these systems also have huge impacts on the ecosystem due to CFC and HCFC emissions. Best alternative for existing VCR based water cooler is the system of evaporative cooling with thermoelectric cooler having affordable cost and eco-friendly. Hybrid water cooler works on the principle of evaporative cooling and Thermoelectric cooling, which provides cold water, hot water and it works as an Air cooler also. Evaporative cooling works on concept of evaporation of water and rate of evaporation is totally depending on humidity of surrounded air. By using evaporative cooling obtain the temperature difference of 8-10°C. During the hot day, the temperature of water in the water tank would be 40°C, then the evaporative cooling alone will not be sufficient to cool the water to 22°C, which is ideal temperature of water for drinking purpose. So, thermoelectric module works on principle of Peltier effect which can produce the temperature difference across its surfaces on applying potential difference across its terminals. As the thermoelectric module produce the temperature difference up to 40°C across its surface, it can easily cool the water to 20°C. More than 60% energy could be obtained by this system in comparison with respect to existing VCR based cooler, so this system can be used as an eco- friendly and cost effective.

Keywords: Evaporative cooling, Thermoelectric cooling, Energy- saving, Eco- friendly

1 Introduction

The water cooler is a device which cools and dispenses water. It is used to provide easy access to drinking water. Water dispensers have become a necessary part of society. It is categorized as bottle less water cooler and bottled water cooler also many water dispensers provide the option to have water immediately cooled or heated, its convenience has become a necessity in many businesses and residential homes. In over span of three decades, there is continuously increase in energy demand due to everlasting population increase. Indian rural areas still the earthen pots are used for cooling water which provide 5-7°C of temperature drop, but during summer season the temperature increases up to about range of 40°C to 45°C. During this season there is increase in demand of cooling equipment's such as water coolers, air conditioner, dispensers, etc. So, taking into consideration common man needs regarding water coolers we propose the system of evaporative cooling with thermoelectric cooler having affordable cost and ecofriendly. There is a range of small evaporative cooler which is used for domestic purpose and large evaporative cooler system for industrial purpose that consumes large amount of electrical energy. Now days energy conservation become a most important research area in industry. More energy consumption is direct affects the creation of an environmental pollution. So, for overcome this problem evaporative cooling is the best alternative. Evaporative cooler works on only 10W electrical consumption and environmentally safe.[1] This invention relates to refrigerating apparatus having a drinking water cooler and a water freezing unit with a single

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control refrigerant. It is an object of the invention to provide improved refrigerating apparatus, in which refrigerant coils of a water freezing or ice unit are connected in series with the refrigerant coil of a water cooler and the supply of refrigerant is controlled by an automatic expansion valve operated by the low-side pressure of the refrigerating system. The features of the invention relate to a refrigerator box and to combinations and correlations of the equipment of the box in a manner. that obtains an adequately refrigerated food or drink storage space, in combination with a drinking water cooler and ice making unit, and with all of the refrigerant for the box, water cooler and ice unit controlled by a single Expansion valve. [2] A water cooler and dispensing system comprises housing, a pump, a cap, a siphon tube, a reservoir, a cooling unit, control circuitry and a faucet. The housing includes a frame and detachable panels for supporting the reservoir above a water bottle. The cap substantially seals the bottle and is coupled to the pump. The pump forces air into the bottle and water upward through the siphon tube to the reservoir. A liquid pumping system may also be used. The reservoir is divided into two portions, and the lower portion contains a cooling unit for chilling the water. The reservoir has an output port from each portion of the reservoir coupled to a faucet formed by a manifold, two valves and a nozzle. The dispenser also includes control circuitry for selectively operating the pump to maintain a predetermined water level in the reservoir. The controller also lights an indicator when the bottle is empty.[3] This paper deals with the evaluation of performance of evaporative cooler at various environmental conditions. The results show that, evaporative cooling works effectively when outdoor air temperature and relative humidity is 27°C to 41°C and 10–60% respectively. According this result, where ambient temperature is higher plate type heat exchanger is required and tube type heat exchanger preferred for low ambient temperature, and design guideline is discussed to determine size of the required tube type heat exchangers at various operating conditions. [4] Along with heat exchanger design, heat and mass transfer analysis is most important factor for the selection inlet air velocity and cooling pad material. Theoretical analysis of the heat and mas transfer between air and water in an evaporative cooler is carried out in this paper. The honeycomb structured wetted cooling pad is used to analysis. The results show that the pad thickness of the pad module and frontal air velocity are two key influencing factors for cooling efficiency of evaporative cooler. Around 2.5 m/s frontal air velocity inlet supply is needed for this pad dimensions. This recommended value decides the frontal cooling pad area, if the air velocity decreases then the large frontal area of cooling pad is required to obtain desired results. But, due to increase the size of cooling pad, overall size of cooler is increases. for cooling efficiency simple correlation is derived, based on energy balance for cooling efficiency. These results are very useful for pre- design of evaporative cooler.[5] Some limitations were found out of conventional evaporative cooler so some modifications are required to overcome this problem. The evaporative cooler was designed and tested at various weather conditions to investigate the performance. This study proposed some suggestions, the horizontal heat exchanger and vertical water spreading configuration is more efficient. The improved design summary chart is used as reference for design of evaporative water cooler. With these modifications COP of system varies from 37 to 78 depending on the various climate and operating conditions. This improved system may achieve sustainable cooling goals. [6]

During summer season and in high humidity climate alone evaporative cooling not able to get desired temperature so thermoelectric cooler (TEC) is added in this system to achieve required temperature. A water cooler is providing with thermo electric heat transfer module for chilling water within a cooler reservoir. The water cooler includes a sensor mounted in a position to detect to build up an ice bank with a cooler reservoir and provide signal to a controller which regulate the thermo electric module to prevent excessive ice bank growth. Water cooler further include an air filter for filtering the air drawn by fan to circulate over a heat sink associated with thermo electric module wherein air filter is adapted for quick and easy excess and removal for a periodic cleaning or replacement. The thermo electric module and air filter

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are include as a part of chiller sub assembly, adapted for quick and easy assembly with water cooler housing for a use in chilling water within the reservoir and also for quick and easy dis assembly from the water cooler housing for service or replacement, if required.[7] Thermoelectric modules are used for heating as well as simultaneously cooling of water. These modules work on the principle of Peltier effect, which converts electric potential difference into temperature difference. Water is cooled by evaporative cooling and then by two thermoelectric modules (TEC1-12706) and for heating of water, it uses the hot side of Peltier module. Thermoelectric coolers are solid state devices, which provide the conversion of the energy without noise or vibration. TECs are not consist any moving part and light in weight. In this paper, TECs are briefly evaluated in terms of different aspects such as type, material, design, modelling, thermal performance, potential applications, economic and environmental issues. The COP of TECs is dependent on the temperature difference between hot and cold side. When the temperature difference between hot and cold side is zero then the COP is obtained maximum.[8] So, in this evaporative water cooler hot water and cold water is delivered and maximum COP is achieved. Design method of thermoelectric cooler is discussed in this paper. Performance curve of TEC which is determined experimentally, utilize to design calculation. Physical properties may determine by this performance test results and for the performance of TEC, empirical relation derived for the analysis of performance of the thermoelectric module. These results may use in the system analysis of TEC using a thermal network model. For the design of TEC, key parameter is thermal resistance of heat sink. The results show that, cheapest heat sink is select for the design of TEC without compromising output of the system. The optimal design cab be done on the basis of maximum cooling effect or heat sink availability.[9]

A combination water cooler and refrigerator unit are provided including a lower cabinet defining a refrigerated compartment, and an upper water reservoir for receiving a Supply of water from a water Source, Such as an inverted water bottle. A refrigeration System mounted within the cabinet includes a chiller coil having a first Segment for chilling the refrigerated compartment, and a Second Segment for chilling water within the water reservoir. In addition, a lower end of the water reservoir is positioned in heat transfer relation with an upper region of the refrigerated compartment, and a single thermostatic temperature control Sensor is mounted within the refrigerated compartment for regulating the refrigeration System for substantially eliminating risk of reservoir or refrigerator freeze up.[10] Hybrid water cooler facilitates eco-friendly, cost-effective and energy- efficient system for cooling as well as heating of water with air cooling facility.

2 Mathematical Model and Design Specifications

2.1 Mathematical Model

We know that, humidity and temperature is the most influence factor for the performance of the evaporative cooling process. So, psychrometric study is required for the analysis of performance of the evaporative cooler in various environment. This paper describes idea about psychrometric process, humid air is considered as a mixture of two gases, the dry air and water vapour. Heat transfer will occur from humid air to wet surface, when the temperature of the surface is different from the air temperature.[11]

Qureshi and Zubair (2006)[12] studied effect of fouling on thermal effectiveness of evaporative fluid cooler and evaporative condenser. They took infinitesimal control volume of evaporative heat exchangers consisting of 3 subsystems having air, water and process fluid.

After applying the water mass balance,

$$\frac{\partial W}{\partial A} = \frac{1}{m_a}\frac{\partial m_w}{\partial A} \tag{2.1.1}$$

The mass flow rate of spray water evaporating into the air is given by

$$dm_w = h_D(W_{s,int} - W)dA \qquad (2.1.2)$$

The simplified simultaneous heat and mass transfer equations for Lewis number equal to unity is as follows:

$$dh_a = \frac{h_D}{m_a}(h_{s,int} - h_a)dA \qquad (2.1.3)$$

Energy balance on the process fluid subsystem is given by:

$$dt_p = -\frac{U_{os}}{m_p c_{p,p}}(t_p - t_{int})dA \qquad (2.1.4)$$

The simplified overall energy balance on the control volume of evaporative fluid cooler is:

$$dt_w = \frac{1}{m_w c_{p,w}}(m_a dh_a - c_{p,w} t_w dm_w + m_w c_{p,p} dt_p) \qquad (2.1.5)$$

The equations (2.1.1), (2.1.2), (2.1.3), (2.1.4) and (2.1.5) describe the evaporative fluid cooler operation. These differential equations are solved by using EES. Different correlations were used to obtain outside tubes heat transfer coefficient and water film mass transfer coefficient. They also did parametric study to evaluate the effects of elevation and mass flow rate ratio in the performance of evaporative heat exchangers. Their experiments have shown that as air gets cooler at high altitudes, less surface area of heat exchanger is required for same amount of process fluid cooling. For different mass flow rate ratios i.e. $[\frac{m_{w,spray}}{m_a}]$ percentage reduction in surface area with respect to surface area at standard atmospheric pressure is found to be almost the same. It means that increasing mass flow rate ratios $[\frac{m_{w,spray}}{m_a}]$ does not have significant impact on lowering outlet process fluid temperature. [12]

Now, $Te = Ts - (Ts - Ti)e^{(-\frac{A_s h}{mC_p})}$

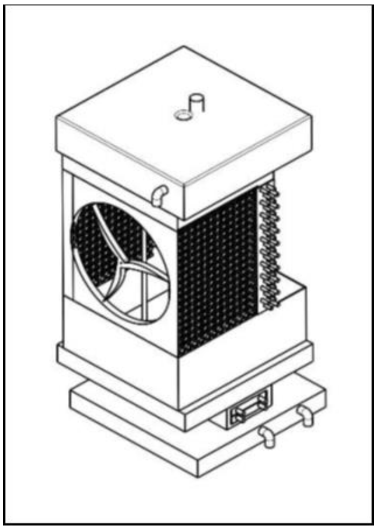
Let, Ti = 35°C and Ts = 19°C

Te = 18.99°C

So, the calculated temperature is equal to wet bulb temperature of air. The length of copper coil of heat exchanger or condenser is correct as the temperature of water reaches near it in 15 min.

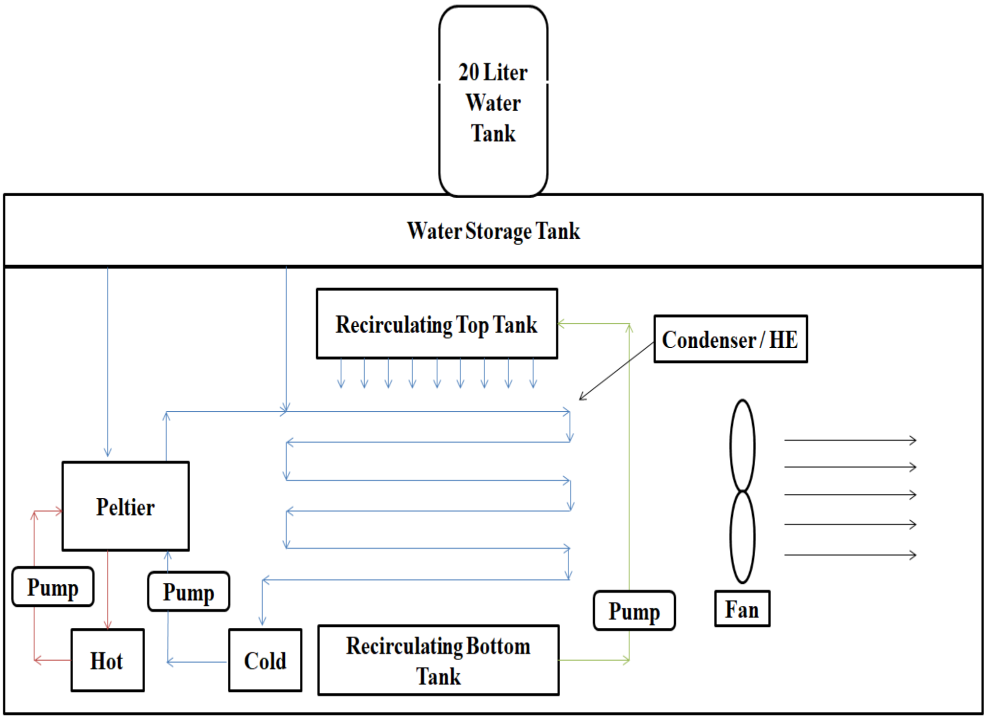
2.2 Design specifications

Design specifications of the hybrid water cooler are: it has a storage tank of 10 liters capacity and two 4 liters capacity tanks for hot and cold water. Dimensions of water cooler are 600mm×600mm×1150mm. The working principles are Evaporative cooling and Thermoelectric cooling. There are two faucets for hot and cold water. Circulating water tank capacity is 25 liters. Mass flow rate, rpm of the fan, Cp of water, the initial and final temperature of the water, length and surface area of copper tubes are the design parameters used for the calculation of the condenser design. According to the calculations it is desired that cold water temperature should reach the WBT of air. The fabricated hybrid water cooler provides cold water of 20˚C to 23˚C temperature which is near to the WBT of air. The water cooler provides hot water and it has an added provision of air cooler also. Body of the water cooler is made with food-grade stainless steel. Electronic control is used for temperature control of the cold and hot water. The system automatically gets shut-off, when the temperature of the water reaches the desired limit and it gets started automatically when the temperature of cold water rises above the set limit. It is applicable for the hot water side also but in the opposite manner. An auto change over circuit is used to switch the power supply from solar to AC mains automatically.



Test Procedure

Experimentation was carried out on this setup shown in Figure 2



Experiments on the setup were carried out by measuring the inlet and outlet temperature by temperature sensors and graphs were plotted to get the exact drop in temperature of drinking water by using the evaporative condenser. The main variables that can be changed for the cooler are fan speed, flow rate of water and length of condenser tube. Humidity is calculated from wet bulb temperature (WBT) and dry bulb temperature (DBT) by using psychrometry chart. Cold water temperature readings were taken at an interval of 5 minutes. After every 1 hour two litres of cold water is replaced with two litres of normal water. This process is carried out at succession of 1 hour throughout the day.

4 Results and Discussion

4.1 Cold water temperature depression

WBT of the air changes at a different time period of the day, so the experimentation is carried out 12 hours of the day by considering this variable WBT of air. Fan speed, a flow rate of the drinking water and the flow rate of the re-circulating water are the fixed parameters in the experiment. According to the experiment the designed water cooler reaches the air WBT temperature within 15 minutes and after that, it continues to provide the cold water of that temperature. The results of cold water temperature drop with inlet water temperature is shown in Figure 3.

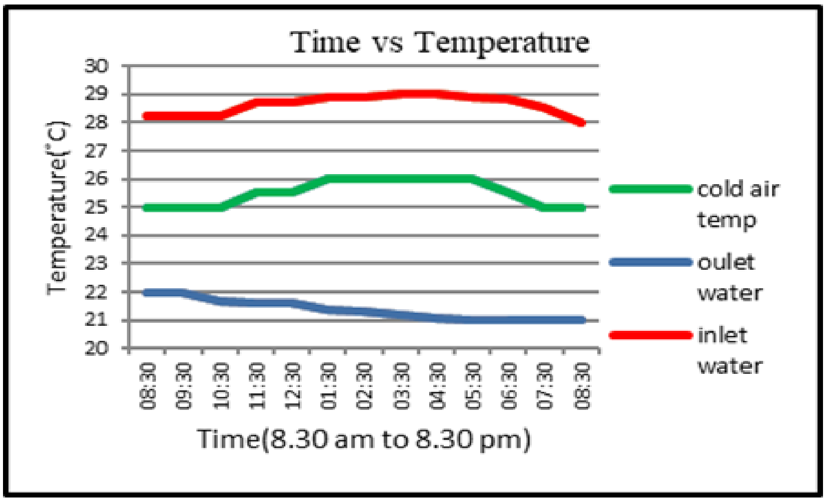


Figure 3: *Graph of time VS temperature of the inlet water, outlet water and cold air*

During hot days, 4 liters of water is cooled up to wbt+0.8°C, which is in the comfort region of drinking water temperature, in 15 minutes. This water cooler also provides air cooling facility. Temperature drop obtained by this air cooler is about 3°C in 5 minutes.

4.2 Hot water temperature rise

Temperature rise for 2 litres of hot water is up to 44°C in an hour. Once the water is cooled or heated it will remain in the same state, ± 2°C due to auto cut-out circuit in spite of the removal of water from the cooler and auto additional of ambient temperature water. Electrical consumption for heating water is high as compare to cooling. The results of heating show in Figure 4.

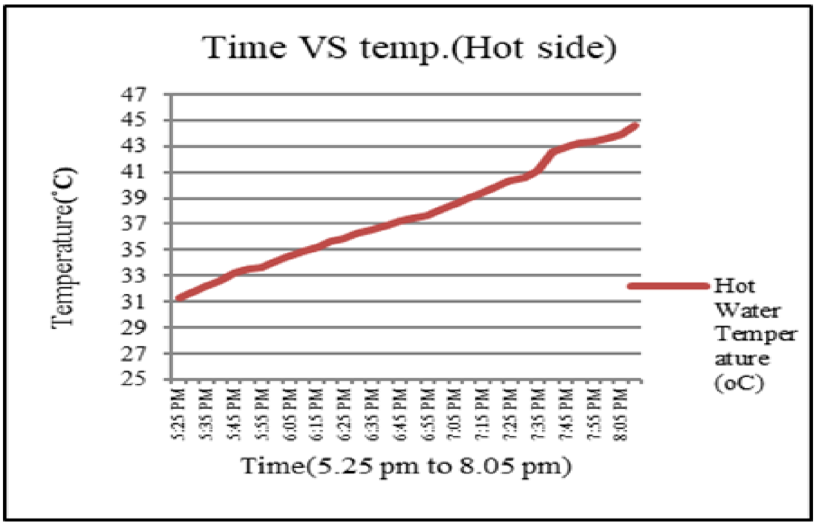


Figure 4: *Time VS temperature graph for hot water.*

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4.3 Effect of Humidity

Climate conditions major influencing factor for the analysis of the performance of the evaporative cooling. Humidity and temperature are most important factors for the performance analysis of evaporative cooling. Some readings were taken in different days having various environment conditions. The results are shown in Figure 5 and Table 1.

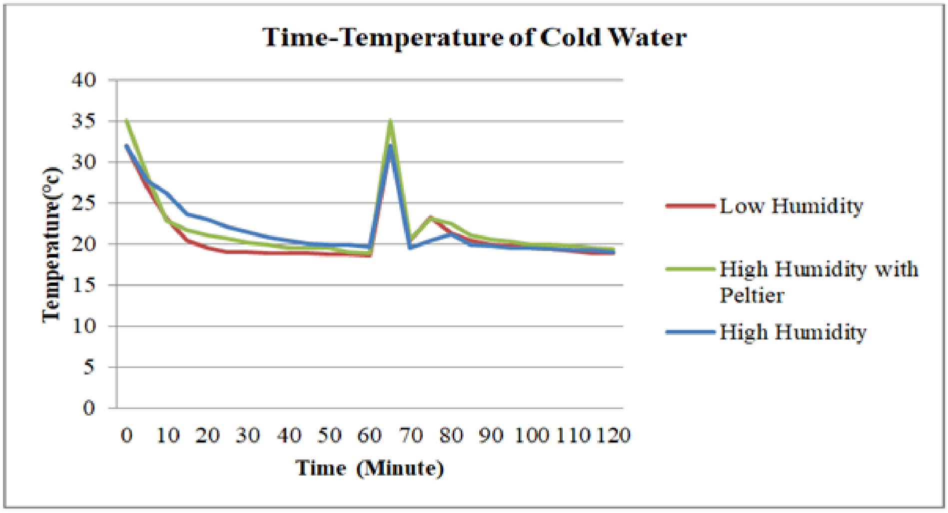

Figure 5: *Temp. V/s Time*

Table 1: *Humidity on different days (Morning) 09:00 AM to 11:00 AM*

Date	DBT (°c)	WBT (°c)	Humidity (%)
13th Jan 2021 -	26	22	70
16th Jan 2021 -	27	23.5	74
19th Jan 2021 -	27	24.5	81.4

Figure 5. shows that, the low humidity environment, within 10 to 15 minutes, evaporative cooler cools the water at desired temperature by evaporative cooling system alone. 30 to 35 minutes required to cool the water at desired temperature by evaporative cooling process alone due to high humidity is present in the outdoor climate. It takes more time as compare to low humidity climate condition. But, combination of evaporative cooling system and thermoelectric cooler i.e. hybrid cooler takes 10 to 15 minutes to cool the water at desired temperature at higher humidity.

4.4 Effect of Mass flow rate

The Mass flow rate is less than 0.8 lit/min then cooler achieve the required temperature drop, but the time required for this temperature drop is more and when mass flow rate is more than 0.8 lit/min then cooler not produced the desired temperature drop in required time. So, the optimum flow rate of water for cooler 0.8 lit/min kept constant to get desired result.

4.5 Comparison of Energy Consumptions

Hybrid water cooler system consumes only 0.05KW power, while also considering water heating system it consumes 0.1KW power, which contributes approximately over 3Rs/day considering water cooling as well as air cooling system, while considering water heating system, cooler contribute approximately over 6Rs/day, which is 67% cost efficient than conventional water cooler which provides only cold water.

Table 2: *Comparison of Energy consumptions of conventional, evaporative and hybrid cooler*

Parameter	Conventional Cooler	Evaporative Water Cooler	Evaporative Water Cooler (With Peltier Module)
Wattage	0.3 kW	0.049 kW	0.1 kW
Working hrs.	6 hrs.	6 hrs.	6 hrs.
Electricity cost per unit	8 ₹/unit	8 ₹/unit	8 ₹/unit
Running Cost Per day	0.3×6×8 = 14.4 ₹/day	0.049×6×8 = 2.32 ₹/day	0.10×6×8 = 4.8 ₹/day
Annual Running Cost	₹ 5256	₹ 858.5	₹ 1750

5 Conclusions

The experimentation was carried out in various climate conditions and different system parameter. The desired temperature of cold water which is 23°C to 20°C achieved within 10 to 15 minutes in low humidity by evaporative cooling system alone. When humidity is higher thermoelectric cooler is used to get required temperature depression. The combination of the evaporative cooling system and thermoelectric cooler (TEC) i.e. hybrid water cooler works efficiently in all environmental conditions. Mass flow rate of water was kept constant at 0.8 lit/min for optimum results. The fan speed kept at maximum of 1450 rpm to get maximum flow rate of air. Energy consumption of hybrid cooler is nearly 67% cost efficient than the conventional water cooler without hot water. Hybrid water cooler does not emit the harmful gases like CFC or HCFC to the environment. So, this system can be used as an environmentally clean and energy efficient.

References

[1] H. Lotfizadeh and M. Layeghi, "Design and performance analysis of a small solar evaporative cooler," *Energy Effic.*, vol. 7, no. 1, pp. 55–64, 2014, doi: 10.1007/s12053-013-9199-5.

[2] H. J. Kellershon, "Series connected ice maker and watercooler," 1952.

[3] M. W. Hancock, S. MacKay, and Y. Muljadi, "Thermo electric water cooler," 1996.

[4] N. Gilani and A. H. Poshtiri, "Heat exchanger design of direct evaporative cooler based on outdoor and indoor environmental conditions," *J. Therm. Sci. Eng. Appl.*, vol. 6, no. 4, pp. 1–9, 2014, doi: 10.1115/1.4028179.

[5] J. M. Wu, X. Huang, and H. Zhang, "Theoretical analysis on heat and mass transfer in a direct evaporative cooler," *Appl. Therm. Eng.*, vol. 29, no. 5–6, pp. 980–984, 2009, doi: 10.1016/j.applthermaleng.2008.05.016.

[6] M. W. Shahzad, M. Burhan, D. Ybyraiymkul, S. J. Oh, and K. C. Ng, "An improved indirect evaporative cooler experimental investigation," *Appl. Energy*, vol. 256, no. January, p. 113934, 2019, doi: 10.1016/j.apenergy.2019.113934.

[7] B. D. Burrows, "Thermoelectric water cooler," 1998.

[8] T. Guclu and E. Cuce, "Thermoelectric Coolers (TECs): From Theory to Practice," *J. Electron. Mater.*, vol. 48, no. 1, pp. 211–230, 2019, doi: 10.1007/s11664-018-6753-0.

[9] B. J. Huang, C. J. Chin, and C. L. Duang, "Design method of thermoelectric cooler," *Int. J. Refrig.*, vol. 23, no. 3, pp. 208–218, 2000, doi: 10.1016/S0140-7007(99)00046-8.

[10] P. Examiner and W. E. Tapolcai, "Combined Water Cooler and Refrigerator Unit," 2005.

[11] J. R. Camargo, C. D. Ebinuma, and J. L. Silveira, "Experimental performance of a direct evaporative cooler operating during summer in a Brazilian city," *Int. J. Refrig.*, vol. 28, no. 7, pp. 1124–1132, 2005, doi: 10.1016/j.ijrefrig.2004.12.011.

[12] B. A. Qureshi and S. M. Zubair, "A comprehensive design and rating study of evaporative coolers and condensers. Part I. Performance evaluation," *Int. J. Refrig.*, vol. 29, no. 4, pp. 645–658, 2006, doi: 10.1016/j.ijrefrig.2005.09.014.

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