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DESIGN AND OPTIMIZATION OF AN ACTIVE EVAPORATIVE COOLING SYSTEM

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ABSTRACT

A research work on the design, fabrication and evaluation of an active evaporative cooling system was carried out for an optimized storage process and improved modus operandi of the system. The cooler is made of an inner wall and external wall, the inner wall is made up aluminum of 0.6mm thickness and the external wall is made up of galvanized steel of 1mm, the internal and external wall is separated by a lagging material called polyurethane of 25mm, the cooler has 3 trays. The water distribution network of the system contains 2 water tanks of 20liters capacity each, a PVC pipe of 25mm diameter for conveying water, a 0.5 horse power pump for circulating water from the bottom tank to the overhead reservoir and a floater switch for controlling the pump. Water is discharged from the overhead tank through a tap and drains through a pad material called jute bag. as water drips through the pad, a suction fan of 38cm swept depth sets air in motion and blows through the wetted part. As evaporation takes place, there is a cooling effect relatively occurring inside the cooling chamber. The cooler was able to control the temperature to 23.70^{0}C relative to the ambient temperature of 29.50^{0}C and relative humidity to 95.6%. compared to an ambient *relative humidity value of 64.7%. The cooling efficiency of the cooler was evaluated on an average to be 86.01%.*

Key words: Active Evaporation, Cooling System, Cooling Efficiency, Temperature, Relative Humidity.

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1. INTRODUCTION

In Nigeria, the deterioration rate of fruits is very high and detrimental to the income of fruit farmers and marketers across the country. Nigeria post-harvest Losses of fruits and vegetables amounts to 35-45% of the annual production. These losses were noted to have occurred during transportation, storage and marketing resulting from poor handling and inappropriate storage facilities [9][6] [11]. Temperature is the measure of thermal energy or heat of the average molecules in a given substance [14]. According to Mareš, [13], temperature in science in fully measured and denoted in the known scales of Celsius (^{0}C), Fahrenheit (^{0}F) and Kelvin (K) [3][18]. Relative Humidity is the ratio of actual pressure of water vapor to the pressure of equilibrium vapor [12]. Temperature of the ambient air, the relative humidity in the air, temperature of water and wind speed are all germane factors to the occurrence of evaporation [10]. Evaporation is said to be active when the surrounding natural air is set in motion as against the natural convectional airflow or movement.

Abdalla and Abdalla [1] developed an evaporative cooler driven by fan. The study focused on the palm leaves suitability for the wetted medium. The study was a success owing to the availability of the agricultural materials use as the wetted medium in Saudi Arabia. The research shows that palm leaves can be utilized as a wetted media owing to its local availability.

Acedo [2] work on two simple ECS with the use of rice husk and jute bag as the wetted medium or pad for cooling in the Philippines for vegetable storage and cooling. The cooler prevented deterioration by using chlorinated water for washing the product.

Olosunde, [19] carried out a research on the key performance evaluation on the absorbent materials in the developed ECS for the effective storage of vegetables and fruits. The study made use of three selected materials as cooling pads: Hessian, jute, and cotton waste. A high-density polystyrene plastic, centrifugal fan, Plywood for covering the walls, the top, basement and the body frame of the evaporative cooler was done with thick wood. Heat load removal, cooling efficiency and the quality assessments of the stored products the performance criteria used in the research. The outcome of the study presents jute material at an overall advantage over all other materials that were used as pad cooling material for the cooler.

Jain [8] carried out a study on a two-stage ECS for the storage and cooing of vegetables and fruits with the use of a heat exchanger. The design in this study is quite expensive as the shelf life of the product was only enhanced for 14days.

Ndukwu [16] did a comprehensive study upon the development of a low-cost Mud Evaporative Cooler for the preservation of vegetables and fruits. The ECS was made up of a double jacket wall with a 15cm gap separating the inside wall from the outside wall to reduce the heat transfer by conduction. The top of the structure is covered with an aluminum foil (75cm long x 67cm x 85 wide) because of its high heat reflectivity. The particular aluminium foil that was used in this research contained pin holes (2.5 mm in diameter) for the exhaust air.

Ndukwu *et., al* [15] developed an Active ECS for a short-term storage of some agricultural products (fruits and vegetables) for a given tropical climate. The designed ESC ultilized palm fruit fiber for the wetted medium with three suction fans, evaporative cooling chambers, automatic water control switch and water pump. Upon evaluation, the temperature of the controlled storage dropped ranged from 4^0C to 13^0C and the relative humidity for the ambient gained an increased to 96.8%.

Several challenges have encountered in the design of a sustainable Evaporative Cooling System for effective storage of fruits and vegetables. According to the research findings of [17], a relative humidity of the controlled environment (ECS) was 83.91% and an average cooling efficiency of 67.17% as achieved. However, the study further recommended and suggested further research into ensuring that the water supply systems be made automated other than the manual process to optimally reduce or eradicated the need of human effort in the entire operating process of the cooling system.

2. MATERIALS AND METHODS

2.1. Design Principles

The principle governing evaporative cooling system is the conversion of sensitive heat to latent heat as shown in Figure 1. The outdoor air which is dry and warm is forced through the pores of the pad material that is wetted by water that is discharged and distributed by the overhead water tank or cooler reservoir. The air passing through the wetted pad is drawn by a suction fan from the environment. In other words, the surrounding air is set in motion by the suction fan and forced through the wetted pad. The sensible heat is a warm and dry air from the ambient that passes through the wetted pad and eventually changes to latent heat because of the occurrence of evaporation which results in the cooling of the chamber.

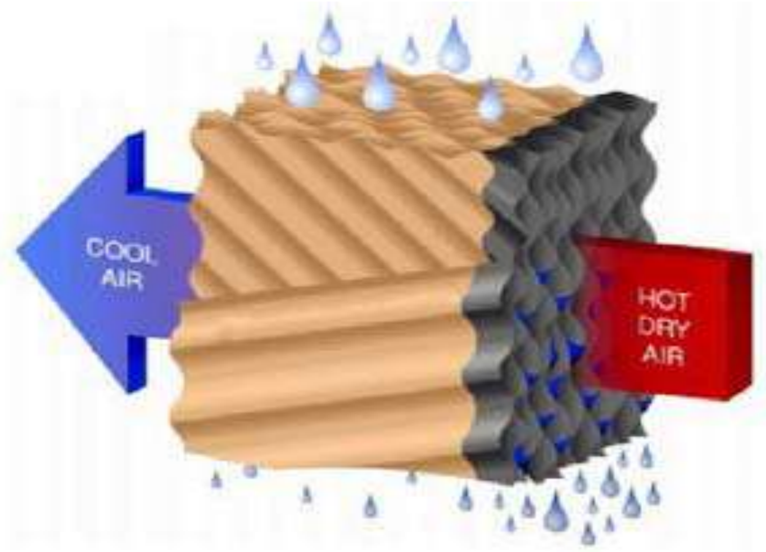

Figure 1 A pictorial representation of the process owing to temperature

2.2. Design Considerations

The following considerations were made during construction of this project,

- Durability and efficiency of the system.
- Surface area for air movement.

- Light in weight (for easy movement)
- Incorporation of water re-circulatory system was also made to reduce or minimize attention.
- A movable frame for mobility.

2.3. Material of Construction

Materials used for construction of this project are presented in Table 1

Table 1 Materials used for construction

S/N	Materials	Quantity Used	Dimension	Notes
1	Galvanized steel	1	4ft by 8ft	Used to make up the external wall of the cooling system.
2	Square pipe	4	1 by 1 inch	Used for the frame work of the entire cooler.
3	Water tank	2	20 liters	It is the water reservoir, both overhead and bottom tank.
4	Angle iron	2		It is used as the base support for the cooler and the pump.
5	Aluminium sheet	2	100 by 100cm	It is used for the inner wall of the cooling system.
6	Suction fan	1	38cm swept depth	Used to set air in motion by drawing the ambient air and forcing it into the cooler through the pad.
7	Wire mesh	1	2 by 1 inch	Made up the frame for the pad that held the
8	Jute bag	4	2cm thickness	Used for the wetted pad material
9	Polyurethane	4	90 by 50cm	It is used as the lagging material to prevent the exchange of heat from the ambient and the controlled chamber through the external and internal wall.
10	PVC pipe	1	1-inch diameter	It is the channel for conveyance of water from the beneath water tank to the overhead reservoir and re-circulated through the same channel
11	Pump	1	0.5hp, 230V	It makes the water circulation effective by drawing the water from the beneath reservoir to the overhead tank.
12	Connecting wire	3	2.5mm core, 3 yards length	Used to connect the fans and the pump to electrical power
13	Tyres	4	80mm diameter	It enables effective mobility of the cooler from one place to another when necessary to change location.
14	Paint	1	1 bucket Silver colour paint,	For the surface finish of the cooler.
15	Plug	3	15 amps	To connect the pump to electrical power.
16	Floater Switch	1		To regulate the operation of the pump by stopping the pump when the water in the reservoir is drained and restarting it when the water level has risen again.

2.4. Design Calculation

2.4.1. Size and Storage Capacity

The cooler was made of cuboid shape so as to create a wider surface for circulation of air [5]. The cooler contains three trays loading fruits and vegetables and a wider space at the bottom to store larger commodities as shown in Figure 2.

Figure 2 Storage Cabinet

2.4.2. Surface Area of Sides of the Cooler

Front side (door)

Parameters; Length = 0.9m, Breadth = 0.5m

Surface Area of the front side = 0.9 x 0.5 = 0.45m^2

Side 1 (right side)

Parameters; Length = 0.9m, Breadth = 0.45m

Surface area = 0.9 x 0.45 = 0.405m^2

Side 2 (left side)

Parameters; Length = 0.9m, Breadth = 0.45m

Surface area = 0.9 x 0.45 = 0.405m^2

Roof;

Parameters; Length = 0.5m, Breadth = 0.45m

Surface area = 0.5 x 0.45 = 0.225m^2

***Floor**;*

Parameters; Length = 0.5m, Breadth = 0.45m

Surface area = 0.5 x 0.45 = 0.225m^2

Back side (pad)

Parameters; Length = 0.9m, Breadth = 0.5m

Surface Area of the front side = 0.9 x 0.5 = 0.45m^2

Total area of component parts = 2.16m^2

Tray;

Parameters; Length = 0.4m, Breadth = 0.35m

Surface area = $0.14m^2$

Three trays have a surface area of $0.14m^2$

2.5. Description of the Evaporative Cooling System

The cooler was majorly made of metal sheets. The external wall was made of galvanized steel with the dimensions (0.5m long x 0.45m wide x 0.9m deep) with a rectangular shape. The inner wall was made of aluminum with dimensions (0.45m long x 0.425m wide x 0.85m deep). The inner and the outer wall were separated with polyurethane to provide lagging for the system to prevent exchange of heat between both walls. The outer wall was painted with silver color to improve reflectivity and reduce rate of heat absorption. Jute was used as the wetted pad. One suction fan of 38cm swept depth diameter was used to drive the ambient warm and dry air through the wetted pad into the controlled chamber. There were two water tanks each of 20litres capacity used, one below the cooler and the other above the cooler as overhead tank or reservoir. A 0.5hp electric pump lifts water from the bottom tank through a 25cm diameter PVC pipe to the overhead tank as water passing through the pad drains back to the bottom tank. The pad was held with wire mesh of 1 by 2 inch to allow air pass through the pad easily. The storage chamber has three trays of dimensions (40cm length x 35cm breadth). The tray was made of 1 by 1-inch square pipe as the frame and a wire mesh of 1 by 2 inches. Figure 3 and Figure 4 show schematic diagrams and exploded view of the evaporative cooling system respectively.

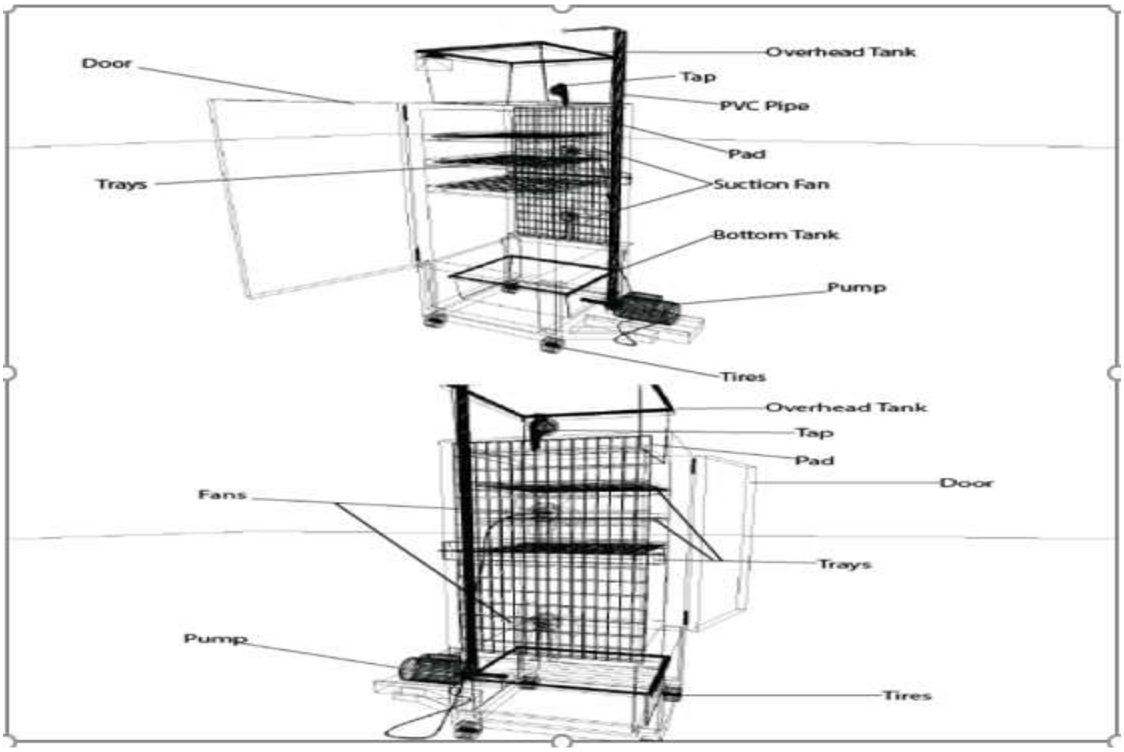

Figure 3 Schematic diagram of an Evaporative Cooling System

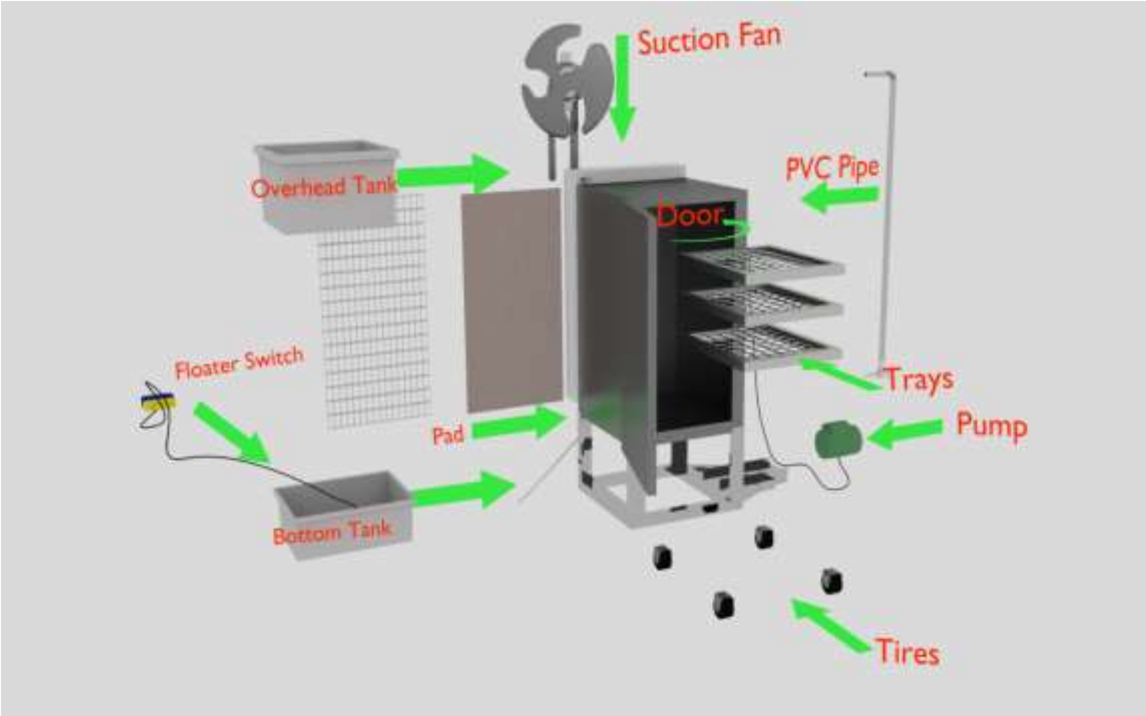

Figure 4 Exploded view of the Evaporative Cooling System.

2.5.1. Pad

The material used for this experiment was jute. The pad is framed with a square pipe of 2.5cm by 2.5cm and covered by a wire mesh of 1 by 2 inch as shown in Figure 5. The pad was made with a thickness of 2cm. it is placed right in front of the suction fans for direct inblow of air through the wetted pad into the controlled chamber.

Figure 5 Jute bag (pad)

2.5.2. Suction Fan

Figure 6 shows that the fan used for this design was a 38cm swept depth diameter powered by electricity. It major work is to draw or suck air from the environment and force the dry, warm air though the wetted pad to cause a cooling effect inside the chamber

Figure 6 Suction fan

2.5.3. Water Distribution

The system has two water tanks that stores water. the overhead tank drips water through a perforated 1” by 1” square pipe into the pad and drain down into the bottom tank through a trough. The water collected at the bottom water tank is then conveyed back to the overhead tank through a 1” diameter PVC pipe. This circulation continues for the system and the pump operation is controlled by a floater switch. The rate of water discharge from the overhead reservoir into the pad is regulated by a tap as shown in Figure 7;

Figure 7 Water Distribution Network

3. RESULTS AND DISCUSSION

3.1. ECS

The active Evaporative Cooling System was eventually designed and fabricated to full design specification

3.2. Cooling Efficiency

The effectiveness of the jute pad is based on the cooling efficiency. The saturation efficiency (SE) of the cooler for the jute bag used was calculated using the formula by [5] as given in Equation 1

$$SE = \frac{\{T1(db) - T2(db)\}}{\{T1(db) - T1(wb)\}} \quad (1)$$

Where;

T1 (db.) = dry –bulb outdoor temperature, °C

T2 (db.) = dry- - bulb cooler temperature, °C

T1 (wb.) = wet-bulb outdoor temperature, °C

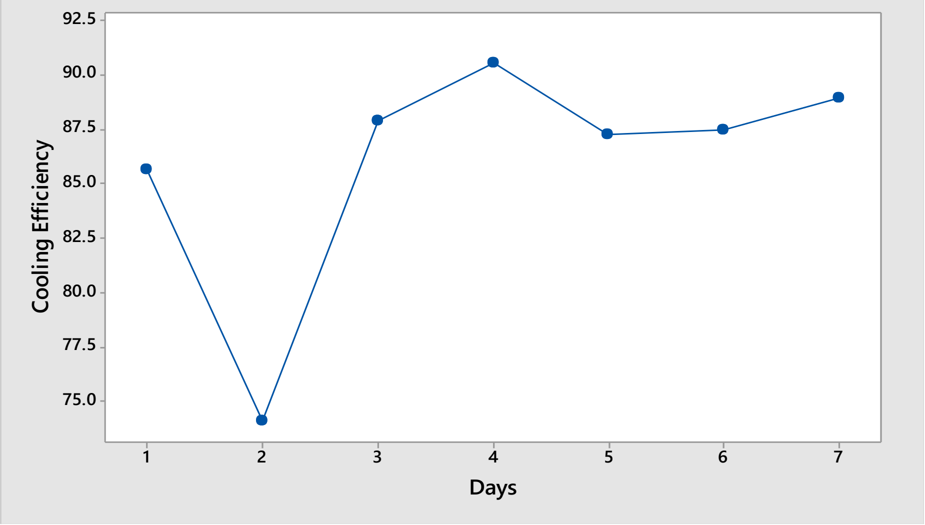

Figure 1 Cooling Efficiency of the Evaporative Cooling System

From Figure 1, it is deduced that the cooling system was able to attain a reasonably high cooing efficiency with the seven days of its no-load performance evaluation. Analytically, the evaporative cooling system had on the average, a cooling efficiency of 86.01%.

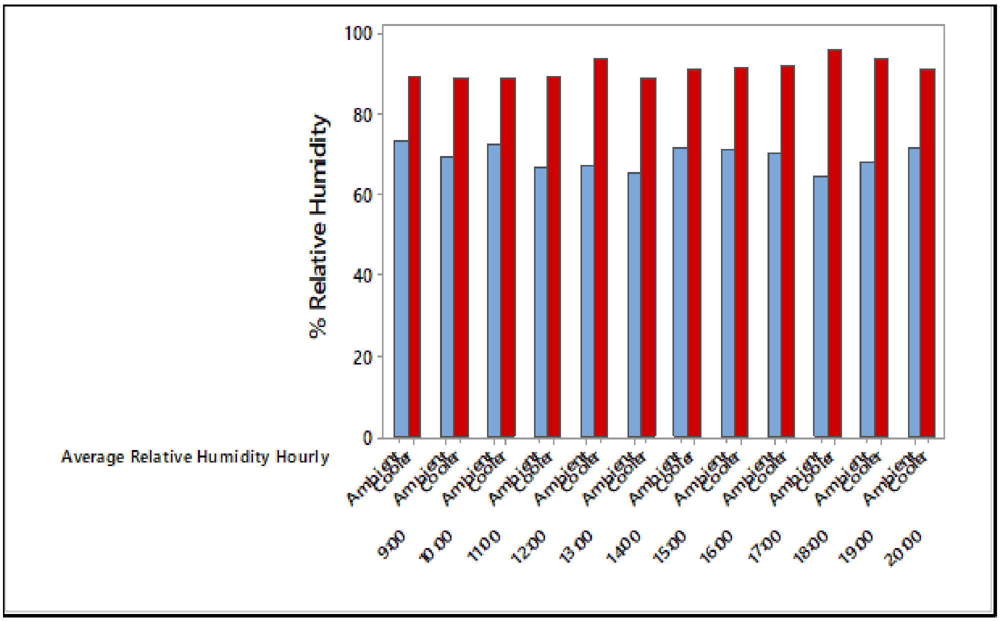

Figure 2 Average relative humidity of cooler and ambience

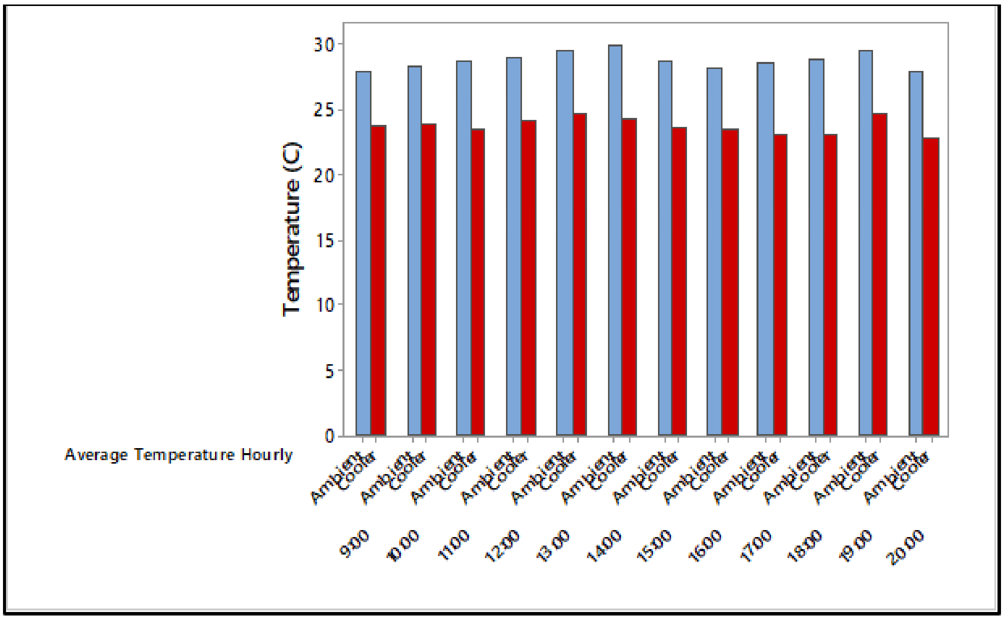

Figure 3 Average temperature of cooler and ambience

3.3. Relative Humidity

The relative humidity readings were taken via the aide of a digital hygrometer. The results obtained for the relative humidity variance between the controlled environment (evaporative cooling system) and the ambience was done experimentally at no-load condition or state of the cooler. The analytical chart of the result is presented in Figure 2.

3.4. Temperature

The relative hotness or coldness of the cooling system and that of the surrounding ambience was meticulously taken with the active utilization of a thermometer. There happens to be a significant variance between the ambience temperature and that of the cooler which really made it a controlled environment. Figure 4 shows the outcome of the test.

4. CONCLUSIONS

The designed active evaporative cooing was successfully designed to attain a substantial improvement on the previous by several researchers. As reported by some researchers that one of the major recommended improvements on the operational effectiveness of evaporative coolers is to design to for an automated water distribution system for the cooler. This work has successfully leveraged on that challenge and had done justice to it by making the distribution of water very automated, hence, reducing the need for human support for its full operation.

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