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DEVELOPMENT OF A WATER AIR-CONDITIONER FOR THE SEMI-ARID REGION OF NIGERIA

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Abstract

The harsh weather condition experienced in Maiduguri between the months of February and June of most years has been a problem to the populace. Buying conventional air-conditioners to ameliorate this problem is difficult for the ordinary people in Maiduguri. In an attempt to lower the temperature of an average $16m^2$ room, an electrically operated water supply cooling system was designed, constructed and tested and was found to make the room conducive for human comfort. Guard sponge was selected and used out of the existing sponges because it has been found to reduce the ambient temperature better than others. Weather conditions of Maiduguri for the past fifteen years and the unreliability of electricity supply were put into consideration in the design of the water air conditioner. The machine was able to reduce the temperature of an average room (16 m^2) by 28% over a period of 42 minutes. The efficiency of the water air-conditioner with respect to the conventional unit is 60%. Seventy five per cent the machine parts were sourced locally, this is to make its production cheap and more affordable to low income earners.

1. Introduction

The natural process of lowering air temperature is by adding moisture (Dossat, 1990). By controlling humidity, cleanliness and even distribution of air in a room, the comfort requirement of the occupant of the conditioned space can be met.

Air conditioning has its origin in the fundamental works done by Robert Boyle, Carnot and others in the 17th century and towards the beginning of the 18th century. During the last twenty years, several developments have taken place in the area of cooling and air conditioning. Earlier works that contributed tremendously in the development of cooling and air-conditioning include those of Chinnappa in India and Australia, Robinson in France and Berger in Thailand (Bridgman, 1941).

Presently, several types of air conditioning processes and systems are available throughout the world. In Nigeria, the common systems used are the central air conditioning, split and window units for both homes and offices (Abdulrahim and Liman, 2002; Gisilambe and Yahaya, 2002). Due to the harsh weather conditions experienced in Nigeria and coupled with the high cost of purchasing a conventional air-conditioning unit, the desire for a conducive atmosphere is becoming illusive to low income earners.

This paper presents the development of a water air-conditioner for use in the semi-arid regions and mainly concerns cooling and humidification of the surrounding air in an average room.

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2. Materials and methods

2.1 Design considerations and machine components

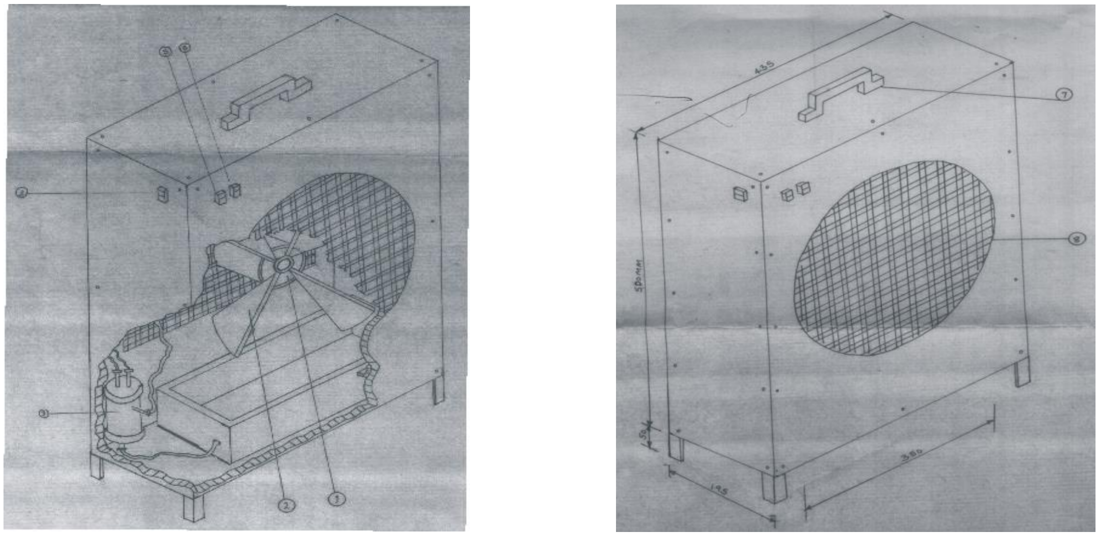
The materials for constructing the machine were chosen on the basis of their availability, properties and economic consideration. The machine was designed for a room size of 16 m^2 and can be operated using dual voltage (12 VDC and 22 VAC). The various physical and mechanical properties of the materials used, namely service life of part, cost and availability of the material and ease of construction, were considered in the design of the air-conditioner (Holowenko et-al; 1961).

The air-conditioner consists of axial flow fan of 160 mm diameter, 10.33 W electric motor, fan shaft of 5 mm diameter, frame, housing, guard sponge, 2-liter water reservoir and feeder pipe of 3 mm diameter.

2.2 Construction and principles of operation

The frame of the air-conditioner, which holds all its components, was made from 19 mm angle iron and it was sprayed with aluminium paint to prevent corrosion. It was drilled at 100 mm intervals to enable fixing of the plastic cover, which was made from 2 mm thick plastic sheet. A 300 mm diameter hole was cut on the front and rear sides to enable fixing of the air-distributor and allow for passage of in-coming air respectively.

A 2 litre PVC gallon was used as the reservoir. The feeder pipe (PVC), which is light in weight and rust-resistant, connects the water reservoir and the pump in-let. The outlet side of the pump was also connected to another PVC pipe with holes drilled at intervals of 10 mm and runs through the entire length of the sponge (300 mm). This is to allow for trickling of water on the sponge. The guard sponge with a dimension of 500 x 300 x 50 mm that provides space for heat transfer was placed at the edge of the back cover inside an aluminium wire mesh brazed on the main frame. The plastic fan was fixed to the frame with the size of fan blade commensurate to the diameter of the air distributor. The overall dimension of the water air-conditioner is 500 x 435 x 195 mm. The complete assembly of the water air-conditioner is as shown in Figure 1.



(a) **(b)**

Key:
1. Fan motor 4. Central switch 7. Handle
2. Fan blade 5. Fan switch 8. Air distributor
3. Eectric pump 6. Pump switch 9. Water reservoir
10. P.V.C. pipe

Figure 1: Semi-sectional (a) and isometric (b) views of the air-conditioner

2.3 Operational principle

The principle of evaporative cooling (Eastop and McConkey, 1999) was employed for the effective working of the water air-conditioner. The pump draws water from the reservoir through the pipe which is connected to the reservoir and sends it through its outlet to the drilled pipe that allows trickling of water unto the sponge. As the sponge gets soaked, the fan sucks air from outside through the sponge and subsequently forces it to the air distributor. The heat transfer process is as shown in Equations 1 – 4 below.

$$Q = Qin - Qout \qquad 1$$

$$Qin = m_a(ha_1 + \omega_1 hv_1) + m_a(\omega_2 - \omega_1)h_f \qquad 2$$

$$Qout = m_a(ha_2 + \omega_2 hv_2) \qquad 3$$

Thus,

$$Q = m_a(ha_1 + \omega_1 hv_1) + m_a(\omega_2 - \omega_1)h_f - m_a(ha_2 + \omega_2 hv_2) \qquad 4$$

Where;

Q = heat transferred during the process,

Qin = enthalpy of air stream coming in

Qout = enthalpy of air stream going out

m_a = mass of dry air in the mixture,

ha = enthalpy of dry air per unit mass of dry air,

ω = Moisture content

hv = specific enthalpy of water vapour

h_f = specific enthalpy of free air.

2.4 Performance evaluation

The performance evaluation of the air-conditioner was out in Maiduguri, which lies on latitude 11^o5^1 N and longitude 13^o5^1 E. The weather in the area of study is very dry between the months of March and June, with annual rainfall of less than 500 mm and very low humidity (about 15% for most months). In the hot season the temperature may be as high as 44^{o}C. (MMC, 1998).

2.4.1 Determination of the rate of discharge of cooling water

This is the volume of water that is completely drained out of the reservoir in a unit time. This can be the water drained out of the reservoir by the action of the pump and onto the sponge by the action of gravity. The rate of discharge of the cooling water is the determining factor of the frequency and time of refilling the reservoir. For the rate of discharge to be determined, the following parameters should be known;

i. cross-sectional area of the pipe

ii. velocity of the water

iii. time taken for the water to drain.

Thus the rate of discharge is given by (Ned and Carlos, 1987);

$$D = AV \qquad 5$$

Where,

D = rate of discharge in m^3/s,

A = cross-sectional area in m^2,

V = velocity of the water in m/s

The most suitable method of finding the discharge rate is by experiment. The discharge time was determined by filling the reservoir with water and opening the control valve of ‘full flow” and measuring the time taken using a stop watch. For this design, the time observed for water to completely drain out of the reservoir was four hours.

2.4.2 Efficiency of the air-conditioner

The efficiency of the air-conditioner was determined using Equation 6 below.

$$R = \frac{T_1 - T_2}{T_1}$$

Where;

R = efficiency of the machine

T_1 = temperature of the hot and dry space

T_2 = temperature of the conditioned space

4. Results and discussion

Table 1: Reduction of the ambient temperature using the water air-conditioner

Initial room temperature (ºC)	Final room temperature (ºC)	Rate of cooling (ºC/min)	Humidity (%)	Time (min)	Efficiency (%)
40	27	13	60	47	32.5
43	29	14	57	41	32.6
37	30	7	50	37	18.9

Table 2: reduction of the ambient temperature using the conventional air-conditioner

Initial room temperature (ºC)	Final room temperature(ºC)	Rate of cooling (ºC/min)	Humidity (%)	Time (Min)	Efficiency (%)
40	15	15	60	20	62.5
43	17	16	57	23	60.5
45	18	27	50	24	60.0

Table 1 shows the reduction of ambient temperature using the water air-conditioner and Table 2 shows that of the conventional unit. When the water air-conditioner was operated for 42 minutes at ambient temperature and humidity of 43ºC and 57% respectively, the temperature of the room was observed to fall by 15ºC**.** In the case of the conventional unit, it was operated at the same ambient conditions and the temperature of the room was observed to have fallen by 25ºC in only

22 minutes. The longer time taken in the case of the water air-conditioner might be due to the improper sealing of the air-conditioner housing and the presence of the whole unit being in the room under observation. This might have increased the humidity of the ambient space. Power requirement of the water air-conditioner is much lower than that of the conventional unit. Despite all these, the water air-conditioner cooling rate was 59% compared to that of the conventional unit.

4. Conclusion and recommendations

The ambient temperature and humidity obtainable with the water air-conditioner can provide the desired comfort in an average 16 m^2 room in a semi arid environment. The water air conditioner developed was able to lower the temperature by about 15^oC using the principle of evaporative cooling. Guard sponge was selected and used because of its availability and ability to reduce the temperature of the air passing through it better than others. Compared to the conventional units that cost between ₦45,000.00 and ₦150,000.00, the water air conditioner is cheaper with a unit costing only about ₦6,000.000 to produce.

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