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Development and Performance Evaluation of a Humidifier for Room Ventilation

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Abstract
The widespread usage of humidifier coolers can help to prevent adding expensive new power plants to the electric grid and the controversial transmission lines that often accompany them. A number of utility companies in areas with hot, dry summers and substantial population growth have programs to promote efficient humidifier coolers. A humidifier with eco-cooling pad using the principle of cooling by evaporation of the wet surface was designed. Materials employed for the development include; a cooling pads cellulose cross-fluted pipes because of its eco-friendly properties and its ability to trap dust, a 0.5 hP blower that permit a constant speed and a submersible feed pump used to supply water with an approximate maximum lift of 1 m high. The water evaporates when in contact with the warm /hot air with the help of blower which brought about the cooling and humidification of the air. The cooling performance was thereafter determined. For cooling by evaporation, the direct saturation efficiency C, which measures the temperature of the air leaving the direct evaporating cooler is close to the temperature of the entering air. Low power consumption and high reliability of the humidifier pads coupled with a wide range of applications including domestic use, remain a special attractions to the humidifier. In addition the humidifier cooler design are a lot easier on the grid than compressor – based cooling systems. In future, the performance of the developed humidifier can be improved by considering the options for thermostatic control and automation as well as flushing of reservoir water to reduce buildup of impurities.

Keywords: compressor, cooler, evaporation, humidifier, thermostatic control.

INTRODUCTION

The global population in the year 2008 hit an unprecedented level of 6.5 billion and this continue to rise drastically and is predicted to hit 9.7 billion by the year 2020 (United Nations, 2008 and 2015). The high rise in population has caused increase in the standard of living of the people and consequently over-congestion of some areas leading to increase in the ambient temperature of the environment thereby causing discomfort of the inhabitants. Generally in Nigeria, there is the high use of the air conditioning unit which is considerably effective but quite expensive with high energy requirement. This brought about the development of an alternative humidifier which uses water for room ventilation. The climatic condition of specific regions in Nigeria demands the use of not just a cooler but a device that can add moisture to the atmosphere and make the surrounding air more convenient and comfortable for habitation. This will enhance good living and the quality of farm products will also improve. In the Northern Nigeria and Middle belt regions with dry and hot climatic conditions, the humidifier cooler can meet both their personal comfort requirements as well as business enhancement. It provides an economical advantage of lesser cost of agricultural produce storage hence helping them to retain their freshness and quality until the day of need arises. Although, humidifiers aid the spread of air borne disease, it brings about proper ventilation to reduce dehydration in work environment such as hospitals and also finds application in the production of semi-conductors (Kwok and Grondzik, 2007). Adequate ventilation and the temperature of work environment is important to increase productivity and reduce work environment related hazards. It also increases the employees' bodily comfort thereby reducing stress and fatigue. McDowall (2006), considered the effects of evaporative and compression cooling while submitting that the degree of the air humidity and temperature determines the efficiency of cooling. Similarly, adiabatic cooling also offers advantages of cost effectiveness, precision control of humidity, environmental suitability and high degree of cooling and humidification hence it is preferred because of the aforementioned merits (Bonan, 2008). Also, according to Grondzik *et al.* (2010), humidifiers are used by paper manufacturers to preserve papers. It is also employed in cold room for food storage and in museum for the preservation of art works. Printers and paper manufacturers use humidifiers to prevent shrinkage and paper curl. Humidifiers are needed in cold storage rooms to preserve the freshness of food against the dryness caused by cold temperatures. In art museums, humidifiers are used to protect sensitive works of art, especially in exhibition galleries, where they combat the dryness (Grondzik, 2010). Humidifier cooling efficiency is dependent on the temperature and humidity of the air introduced (Chen *et al.,* 2014; Rabhi *et al.,* 2015). It is important to note cold humid air has lesser capacity to absorb moisture when compared to warm dry air than cold humid air, hence, warm dry air has a greater tendency to be cooled. The cold water humidifier on the other hand boast of efficient energy consumption and cost effectiveness (MC Dowell, 2006; Proracki, 2010). It is environmental friendly and also has the benefit of correct humidity control as both high and low humidification have an adverse effect on man. According to Krigger and Dorsi (2004), the rate of evaporation is influenced by the measure of the relative humidity. An environment with high humidity will have a lower rate of evaporation when compared to an environment with low humidity. Also, Maheshwari *et al.* (2001) developed an inverse relationship between the humidity and water vapour in an environment. Increase in humidity of a room decreases the water vapor and vice versa. For optimum efficiency, periodic checks and maintenance should be carried out on humidifiers. For instance, the packing material in the humidifier which provides more surface area for hot water which facilitates exchange of heat and mass transfer between hot water and air must be checked periodically (Chiranjeevi and Srinivas, 2017). Also, the wicks of an humidifiers needs periodic cleaning or replacement to ensure free flow of air otherwise the humidifiers efficiency may reduce as mineral deposits may fill up the spaces in between hindering air circulation.

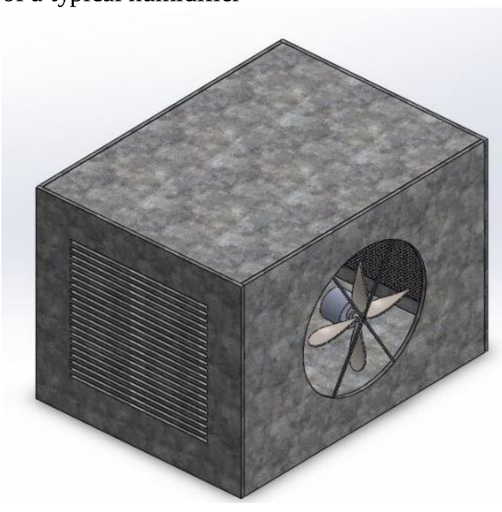
The American Society of Air Conditioning and Refrigeration Engineers (ASHRAE, 2016) recommended 45% - 55% relative humidity level so as to prevent sparks that can destroy electronic equipment. Also, EIA (2004) opined that excessive use of humidifier can raise the relative humidity level, which can cause adverse health conditions, therefore a relative humidity of 30% to 50% is recommended for most homes. Cooling pads paly important role in ensuring incoming air is hot and dry. Temperature reduces significantly when hot and dry incoming air is made to pass through the wetted cooling pads. The reduction in temperature to 10^o– 20^oC (50^o– 60^oF) can be achieved by passing through the wetted pads (ASHRAE, 2012).The aim of this work is to develop a cost effective humidifier developed from locally source materials. The sustainability and novelty lies in its local material source, environmental sustainability, ability to meet increasing demand for cooling systems, low power consumption, cost effectiveness and high reliability of the humidifier pads coupled with a wide range of applications including domestic use, remain a special attractions to the humidifier.

METHODOLOGY

The idea behind the model is to design humidifier cooler which uses humidifier cooling to provide an airflow that is cooler than the surrounding air. When air blows through a wet medium: a cooling pads cellulose; some of the water is transferred to the air and its dry bulb temperatures is lowered. The rate of cooling lies in the temperature difference between dry bulb and lower bulb temperatures. The air on losing the temperature get cooled and the evaporated water is mixed with air and thus the air get humidified. The cooling performance was thereafter determined. A blower inside the unit pulls outside air through the sides and into the house. To produce cool air, each porous side is fitted with a pad of water-absorbing material. Water is stored in a sump tank is lifted with a pump to the top of each side. For effective cooling, each pad needs to remain damp, but not soaked. Dampness creates the most evaporation, therefore, the most cooling.

For cooling by evaporation, the direct saturation efficiency C, which measures the temperature of the air leaving the direct evaporating cooler is close to the temperature of the entering air.Evaporative cooler thermostats, available at many hardware stores, automatically turn off the cooler when the air reaches a desired temperature, making operation much more efficient. Most evaporative coolers without thermostats have separate switches for the fan and pump. If the unit lacks a thermostat, the pump can be allowed to run a few minutes before turning on the fan. This saturates the cooler pads.

Figure 1 is the prototype 3D rendition in solid work of a typical humidifier



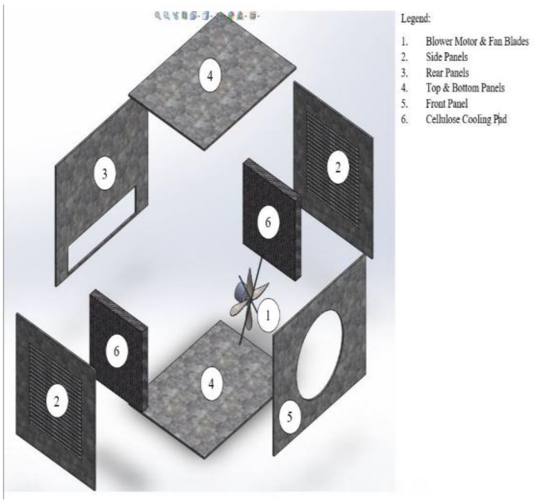


Figure 1: 3D Prototype of the humidifier

Materials employed for the development of the humidifier

1. The body is made of galvanized steel to prevent any form of chemical reaction and because of its low electrical conductivity.
2. The cooling pads is a cellulose cross-fluted pipes because of its eco-friendly properties and its ability to trap dust.
3. The blower of 0.5 Hp that permit a constant speed and it is resistant to corrosion.
4. The submersible feed pump used to supply water with an approximate maximum lift of 1m high.
5. The prototype was produced by bending and coupling of some parts to limit the use of welding and reduce the possibility of leakages where necessary.

The developed humidifier is shown in Figure 2.

Figure 2: The developed humidifier

Design Characteristics and Calculations of Evaporating Cooling System

1. Rate of air exchanged: The prototype is designed to moderately humidify a room of 0.311 cubic metre per minute and a volume of 0.7787m^3. The air changes per hour is expressed as Equation 1.

$$\text{Air Changes/ Hour} = \frac{CFM}{Volume\ of\ room} \quad (1)$$

$$\text{Air Changes/Hour} = \frac{0.311}{27.5} = 0.0113 \text{ ac/h}$$

The component falls within the range of humidifiers used for the cooling of office space and classrooms.

2. Elevation: As the height increases, the volume of air needed will also increase beyond the volume required at normal elevations.
3. Temperature Increase: Temperature increases with decrease in the air flow rate. The value of temperature is adjustable to the desired value. Usually a -13.88^{o}C increase in temperature is generated.
4. Pad to blower distance: The pad and blower are located parallel to one another with a clearance of 0.1 m left on each side from the pad to the blower. This is to create a more air tight chamber that permits higher pressure built up inside the chamber by directly allowing suction of more ambient air through the cooling pads at a faster rate.
5. Pad Design: The sum total of the volumetric rate of air flow through the blower divided by the volume of air flow through one square metre of pad per minute determines the pad size.
6. Pump Capacity: The pump is delivered at the top of a 0.0762 mthick pad and at a volumetric flow rate of 2.0 $\times\ 10^{-3}$cubic meter minute per linear m of pad. For a length of the pipe: 200mm, 375mm water distribution pipe is required. 18,000 mm is the longest recommended pipe length. At every 0.00508 m, 0.003175 holes are made in pipe.
7. Sump Tank Volume : The sump was designed to hold at least 40$\times\ 10^{-3}$ cubic millimeter of distilled water, hence the design considerations of making it 381mm in height and 76mm in width avails the prototype to hold a total of$44\ m^3$ of water.

Psychometric Calculations on the Humidity Produced

Cooling performance can be predicted from standard weather reports. This is because this report always contain the dew point and relative humidity. The value of the wet bulb temperature can be obtained using a psychometric chart. The cooling performance can thereafter be determined when the value of the dry and wet bulb temperatures are the same or approximately close to each other. For cooling by evaporation, the direct saturation efficiency$C$, which measures the temperature of the air leaving the direct evaporating cooler is close to the wet temperature of the entering air. The direct evaporative cooling saturation efficiency is expressed as Equation 2.

$$£ = \frac{T_{e,db} - T_{l,db}}{T_{e,db} - T_{e,wb}} \quad (2)$$

Where:

£ is the direct evaporative cooling saturation efficiency (%); $T_{e,db}$is the temperature ofair dry bulb at the entry (^{o}C); $T_{l,db}$ is the temperature of air dry bulb at the exit (^{o}C); $T_{e,wb}$ is the entry air wet bulb temperature (^{o}C)

The cross fluted cellulose pad to be used in design prototype has a factory tested efficiency of 89%. Solg for the temperature of air released to the environment by the system can be gotten by using psychometric chart:

Effect of Location on the Degree of Humidification

The performance evaluation of the humidifier was conducted in a closed room of 15m^2, using the normal speed mode. The value of humidity of the closed room at different time was measured and the result compared with the location humidifier.

Effect of Location on Air Flow Rate

The flow rate and rotation at normal speed mode of the original air conditioner with humidifier placed on top and at the bottom were measured. The result is presented in Table 1.

RESULTS AND DISCUSSION

Table 1 presents the result obtained from the variation of the location of the humidifier. When the humidifier was placed on top, changes in the flow rate is negligible. On the other hand, when humidifier was placed at the bottom, the flow rate increases significantly. Some air leaks from the web film reduces the flow rate through the evaporator. The Table also shows that none of the locations has effects on noise. Combining all the experiments, it is observed that the efficiency of the humidifier placed on top of the air conditioner is slightly better than when placed at the bottom due to the even distribution of cool air across the room.

The dry bulb and wet bulb temperature as taken with a thermometer as

$T_{e,db}$= 34^{o}C; $T_{e,wb}$= 28^{o}C; efficiency e = 85%

Therefore the exit air dry - bulb temperature is calculated as

$$T_{l,db} = 34 - \{\{ 34- 28) \times 0.85\} = 28.9^{o}C$$

This means that the humidifier can cause an efficient cooling of the dry bulb temperature from 60% to 70% throughout the operations.

Table 1: The Flow rate parameters at difference conditions

	Scheme	Flow rate (m^3/h)	Power (W)	Revolution n/h)
Humidifier on the bottom	Normal Speed	420.8	29.0	98
Original	Normal Speed	310.5	29.6	107
Humidifier on	Normal Speed	310.9	29.4	118

From Figure 2, the power required is observed to decrease with increase in flow rate.

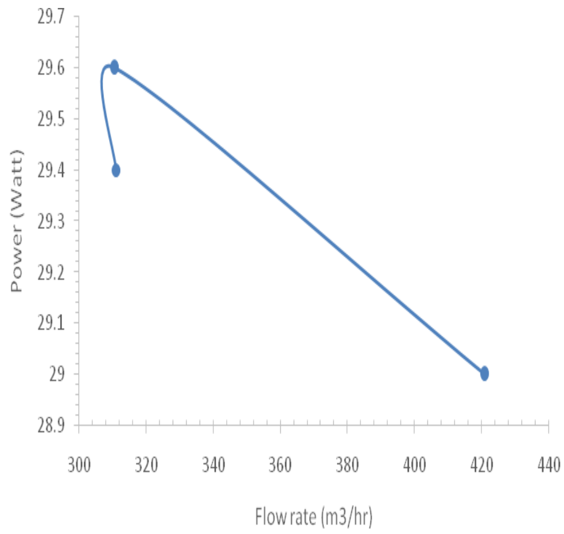


Figure 3: Power required at different flow rates

Table 2 presents the level of noise when the humidifier was placed on top and beneath the air condition.

Table 2: Noise comparison with different locations

Scheme	Noise (dB)	
Original	Normal Speed	41.5
Humidifier on Top	Normal Speed	42.3
Humidifier on Bottom	Normal Speed	42.3

Figure 4 shows the noise level at different locations. The noise level was observed to increase when the humidifiers was moved from its original to the top and bottom of the air condition system. At the top and bottom, there was no significant changes in the noise level.

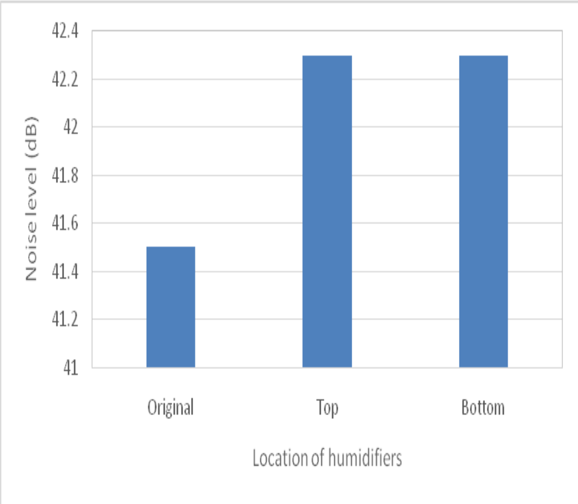


Figure 4: Noise levels at different locations

CONCLUSION

The research has provided an initial analysis into the development of a humidifier with cooling pads integrated using an efficient air blower, cooling pads, water storage, feed pump, wind outlet etc. It has also provided realistic opportunity for eco-cool humidifier cooling pad using the simple principle of humidifier cooling system optimization. The efficiency of the humidifier placed on top of the air conditioner is slightly better than when placed at the bottom. The performance of the developed humidifier is highly efficient raising the humidity level in the room under heating condition and constant cooling conditions. The developed humidifier is cost effective based on the fact the power consumption is relatively low and the materials for its development are sourced locally.

The successful completion of this work brought about the generation of design data for scaling its future development. It is considered effective in terms of cost and energy conservation than mechanically driven compressor. In addition, the developed humidifier cooler also offers advantages of cost effectiveness (in terms of development operation and maintenance), precision control of humidity, environmental suitability, relatively simple technology for development and installation as well as high degree of cooling and humidification. However, sourcing for local materials with the desired mechanical properties for use in some parts of the humidifier was a challenge hence the reason for limiting the humidifier to an experimental test rig for scaling its future development. In addition, there is reduction in temperature control unless fitted with thermostat and the air pulled inside by the blower may not be as clean as when compared with the operation of the conventional air conditioning system. It also requires more maintenance as there is need, periodically change the cooling padsandopen windows or vent to outside during usage as damp air can cause doors or furniture to swell or smell.

RECOMMENDATIONS

It is recommended that humidifiers of this nature should be provided in large quantity for commercial purpose because of its comparative advantage to that of its substitute, affordability and less power consumption. In future, the performance of the developed humidifier can be improved by considering the options for thermostatic control and automation as well as flushing of reservoir water to reduce buildup of impurities.

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