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IMPROVING THE POWER EFFICIENCY OF A LOCALLY FABRICATED COOLING SYSTEM FOR LARGE HALLS

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ABSTRACT

This paper presents an alternative way of improving the power efficiency of a cooling system for large halls. A prototype system was developed that utilizes a combination of direct evaporative air cooling and displacement ventilation system. This system strategically uses the application of water on a cooling pad to absorb latent heat from the air space and thus reduce temperature. The system was automated with a microcontroller based device to improve power efficiency for optimal cooling. The efficiency of the system was determined with respect to the weather condition and season times. An average cooling efficiency of 52.9% was attained using 142W of power for a hall of 30 ft × 76 ft × 12 ft.

1. INTRODUCTION

For cooling to be carried out, energy is required to remove the unwanted heat from the area to be cooled. The high cost of energy makes it necessary to critically measure and minimize the amount of power consumed by cooling systems. Thus, there is a high demand for power efficient systems that can provide the required cooling for large halls. The most common technique that has been employed include the use of ceiling fans for ceremonial halls and large classrooms, as this primarily consumes less energy compared to other cooling systems. In factories, some of these fans are used as vents to remove both heat and contaminated air within the enclosure. However, industrial vapor compression units are used in banking halls and churches, providing low temperature but high energy consumption. The need for comfort has facilitated the inquisitive growth and development of techniques for effective cooling for homes, offices and factories. This curious desire has been able to generate some of the following methods which include evaporative cooling, refrigeration cooling, desiccant cooling, ceiling fan technology, variable air volume system, chilled ceiling cooling etc.

These various systems have been implemented over the years, and most importantly, the cooling rate, cooling efficiency and energy consumption varies at different levels in different regions of the world due to climatic conditions. The climatic change entails basically, the temperature and humidity levels of the various geographical regions on the earth surfaces. In humid regions, combined refrigeration and desiccant cooling is more rampant as this helps to reduce humidity when temperature is high, as high temperature and high humidity causes less vaporization of body sweat (Maheshwari et al., 2001). Another common method is the use of ceiling fans to drive air across the enclosure to enhance vaporization through fast movement of air across the heated body. This ceiling fan method consumes less energy compared to conventional refrigeration techniques but has low cooling capacity, especially in high temperature. In most cases, to improve efficiency in systems, a combination of two or more methods is used, beaconing on the advantages of both systems. Archibald (2001) used a new desiccant evaporative cooling cycle for solar air conditioning and heating by creating two dry air streams. Indirect evaporative cooling of one air stream is used to cool the second stream so that cool and dry air can be delivered to the building. Causone et al. (2010) also combined the radiant floor cooling and heating with displacement ventilation. These systems are usually designed to work with specific environmental conditions such as desiccant cooling in high humidity and evaporative air cooling system in low humidity and high temperature.

Another way of enhancing the performance of these systems is the method of ventilation used. One of the most effective methods is the displacement ventilation which entails input of air from the base of building and a vent at the top of the building. Displacement ventilation helps to separate clean air from the contaminate air as the air rises from the base to top of the building (Niemelä et al., 2001; Causone et al., 2010). It can be applied in different fields such as factory, ceremonial halls and offices. These techniques are suitable for factories that employ open loop cooling system as well as ceremonial hall with good ventilation systems as to reduce mucus, decay and growth of micro-organisms which threatens the health of its inhabitants. Evaporative cooling provides many benefits compared to other systems. This cooling method is long-established with implementation such as porous water pots, water ponds, pools, and thin water chutes (Duan et al., 2012). Evaporative cooling can be classified into two major forms: the direct evaporative cooling and the indirect evaporative cooling. The former employs direct application of water to the air, while the later uses surface plate(s) to separate the working fluid (water) from the air being cooled. A major problem encountered in cooling systems, is the sizing of the air conditioner. This implies that a proper enclosure needs a certain value of the cooling system rating to provide a comfortable environment. Hence, this paper presents an alternative way of improving the power efficiency of a cooling system for large halls.

2. MATERIALS AND METHODS

The prototype cooling system was developed using a combination of evaporative cooling and displacement ventilation. The materials used for the system included an electric fan, a cooling pad, an ATMega 32 microcontroller-based control device, a DC powered water pump, a plastic drain box and a wooden enclosure. To reduce power consumption, a switching technique that regulates the operation of the system as it interacts with the environments was employed. After experimentation was carried out, a temperature of 28°C was chosen as an appropriate temperature to produce a perceivable cooling effect. The switching is described as follows:

i. Switch on fan and pumps when relative humidity is less than 80% at all temperatures
ii. Switch on fan only when relative humidity is greater than 80% and temperature greater than 28°C degree Celsius.
iii. Turn off system if relative humidity is greater than 80% and temperature less than 20 °C to conserve power.

The switching pattern was implemented with a microcontroller-based control device which is comprised of a temperature sensor, humidity sensor, solid-state relay, microcontroller, water pump, electric fan and an LCD display. The schematic used for simulating the switching operation of the prototype is shown in Figure 1. An Arduino UNO embedded board was used for the simulation of the circuit using the Proteus software (version 7.7) developed by Labcenter Electronics. The LEDs that were used to represent the fan and pump turned ON an OFF according to the switching technique during the simulation.

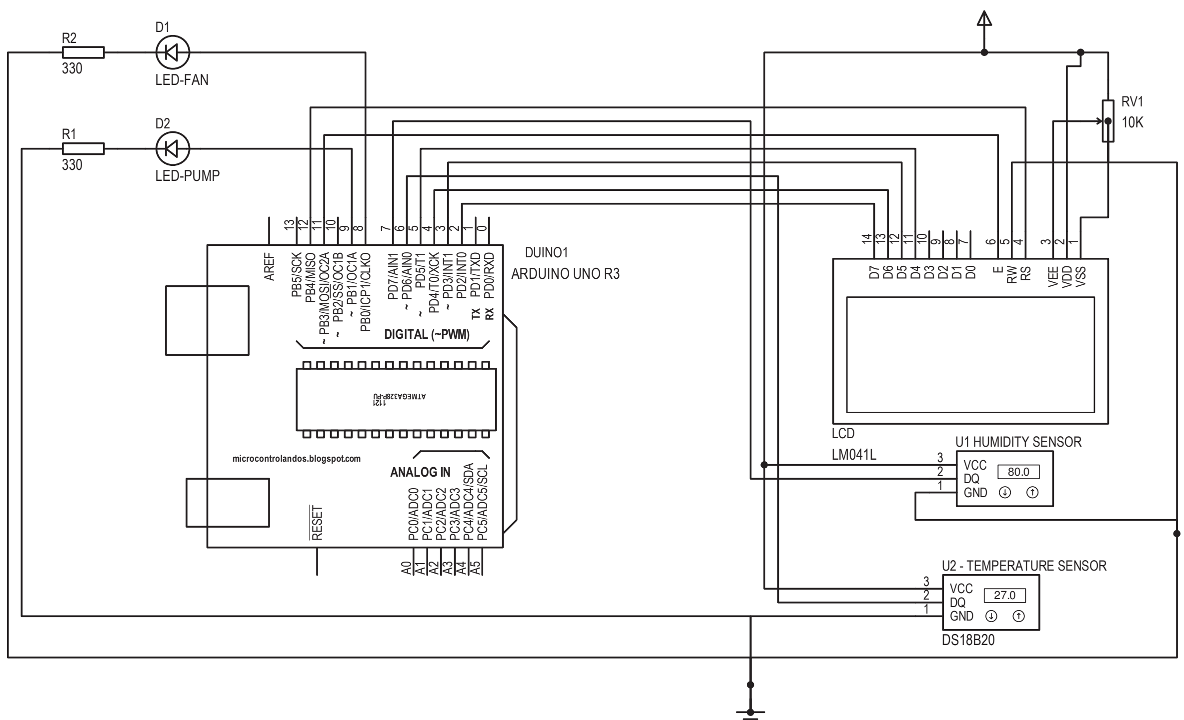

Figure 1: Schematic used for simulation of the prototype cooling system

2.1. Principle of Operation

The working principle of the developed prototype is illustrated in Figure 2. Dry air was passed through the moistened cooling pad to the interior of the hall space to be cooled. As the air passes through the pad, there will be a supply of cooled air from the base of the hall. The vents at the top of the hall allow the escape of warmed air and proper ventilation in the building. The prototype was built using locally sourced materials as shown in Figure 3.

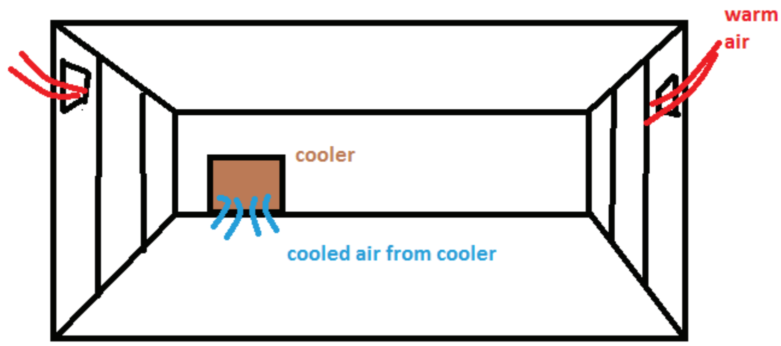

Figure 2: Working principle of the prototype for a hall of 30 ft × 76 ft × 12 ft.

2.3. Calculation of cooling efficiency and Dew point

The cooling efficiency of the system and the dew point was calculated using Equation (1) and Equation (2) respectively (Handbook, 2001):

$$E_o = 100 \times \frac{(t_1 - t_2)}{(t_1 - t)} \tag{1}$$

$$T_d = \frac{B_1\left[\ln\left(\frac{H}{100}\right) + \left(\frac{A_1 \times t}{B_1 + t}\right)\right]}{A_1 - \left[\ln\left(\frac{H}{100}\right)\right] - \left[\left(\frac{A_1 \times t}{B_1 + t}\right)\right]} \tag{2}$$

Where: E_o (%) is the direct evaporation cooling effectiveness, t_1 (ºC) is the dry-bulb temperature of entering air, t_2 (ºC) is the dry-bulb temperature of leaving air and t (ºC) is the wet-bulb temperature of entering air. For Equation (2), T_d is the dew point temperature, H is the relative humidity, A_1 and B_1 are constants with values 17.625 and 243.04 respectively. The relative error of the calculation is 0.4% for the temperature range of -40 ºC $\leq t \leq$ 50 ºC. Testing was carried out in a 30 ft × 76 ft × 12 ft hall in July, 2016 at Urora community, Benin City, Edo State, Nigeria.

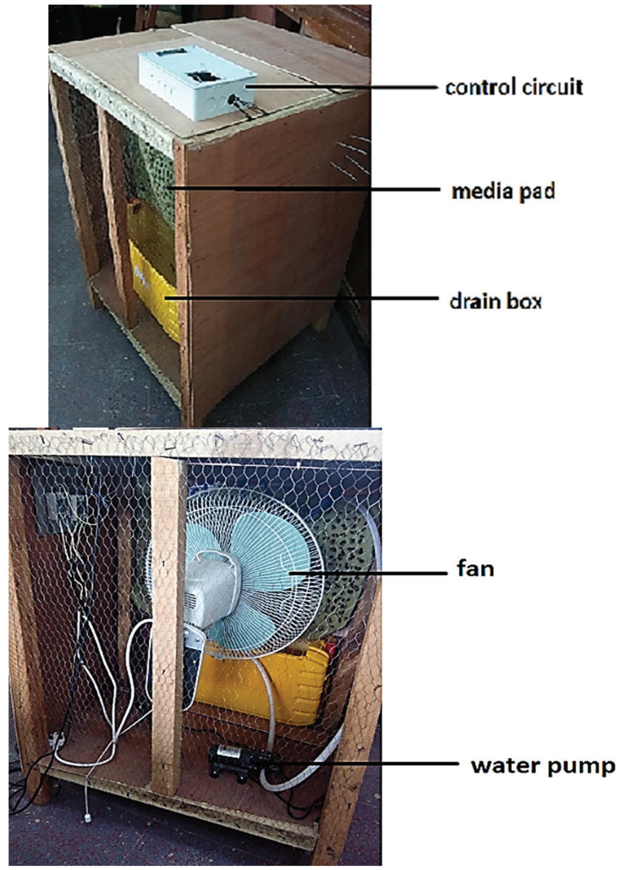

Figure 3: Prototype of the cooling system (a) back view, (b) front view.

3. RESULTS AND DISCUSSION

The test results for the developed prototype cooling system are summarized in Table 1. In Table 1, H_1 and H_2 represent the relative humidity at t_1 and t_2 respectively. The dew point temperature (T_d) as of 6:00 am and 2:00 pm were obtained as 24.045°C and 22.835°C respectively. These were calculated using values of the initial dry bulb and initial relative humidity from Table 1. The power consumed by the developed prototype is presented in Table 2. The total power consumed by the prototype was 142 W.

Table 1: Test results for cooling system prototype

t_1 (°C)	t_2 (°C)	t (°C)	H_1 (%)	H_2 (%)	E_o (%)	Time of operation
26	25.0	24.6	89	91	71.4	6:35 am
27	26.5	24.1	78	80	34.4	2:00 pm

Table 2: power consumed by prototype

Item	Power consumed (W)
Fan	95
Pump	42
Control circuit	5
Total	142

Figure 5 shows a comparison between the developed prototype and other cooling systems in terms of power consumption at a cooling efficiency of 52.9% for the test environment. The results show that the power consumption is very low compared to other cooling systems. To put the power consumption in perspective, the prototype consumes a mere 142 W (0.14kW). This compares favorably with the ceiling fan and vapor compression systems with power consumption of 1.2 kW and 24.54 kW respectively. Hence the prototype is more power efficient. However, a major limitation of the prototype is that it only delivers a cooling efficiency of 52.9%.

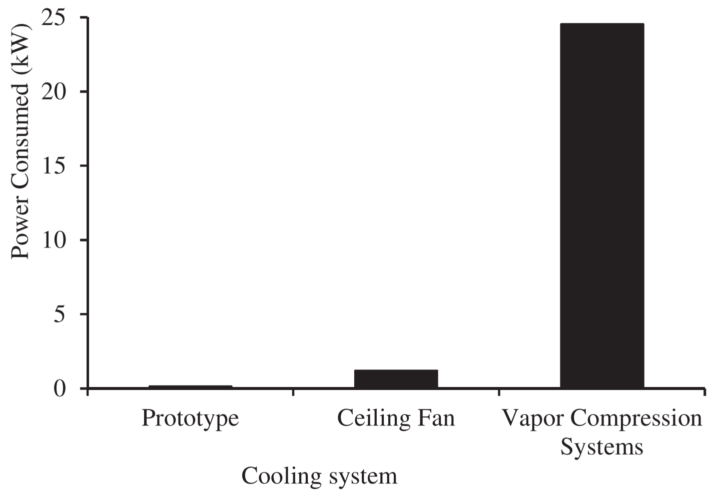

Figure 5: Power consumed by prototype compared with other systems

4. CONCLUSION

The energy required to cool a large hall varies based on the type of cooling system used and climatic conditions. One method of cooling that offers the advantage of lower power consumption is the evaporative cooling method. This paper has presented a prototype cooling system that demonstrates the practicality of combining this method with displacement ventilation and how improvements can be made on its power efficiency. The results show that the developed prototype cooling system presented in this paper performs better than the ceiling fan and vapor compression systems in terms of power consumption. The developed cooling system can be deployed in large halls such as factories and ceremonial spaces.

5. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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