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Solar-Powered Cooling System for Residential Building

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Abstract. High power consumption cooling devices such as air conditioners increase electricity power demands. In this project, an alternative solar-powered cooling system is suggested to reduce the air temperature to human comfort level and reduce their household electricity usage. Plants are used in this project to undergo transpiration, which is a natural process where moisture is carried from the roots to the underside of the leave to be evaporated. Heron's fountain technique was applied to reduce the power consumption of the water pump by lifting up water using gravity. Power consumption is reduced to 23 watts per hour and the air temperature around 1 °C to 2 °C of a 90 square feet single bedroom depending on the surrounding condition. This gives human a range of thermal comfort of 25 °C to 29 °C in residential buildings..

1. Introduction

Nowadays, cooling systems that are widely use in the world and are very popular is air conditioner. The ownership level of air conditioner in housing area had also increase but unfortunately the high power consumption makes it a burden as it increases the cost of electricity bills. Alternative ways to decrease the power consumption is by switching cooling system to evaporative coolers.

Evaporative coolers use the evaporation of water to decrease the temperature of the surrounding. Some ways in implementing the evaporative cooler is by using the transpiration of plant. Transpiration is a process by which the moisture is carried through plants from roots to small pores on the underside of the leaves, where it changes to vapor and is released to the atmosphere. It is essentially evaporation of water from plants. This project intends to design an evaporative cooler that uses solar energy as a power source and uses plants as a cooling medium to cool the air surrounding.

1.1 Air conditioner usage

Based on a study about the energy consumption and air conditioning usage in residential buildings of Malaysia [1], two surveys were conducted in Johor Bahru. The first survey was carried out on October 2004 to understand the occupants' behaviors about air-conditioning usage [1]. The second survey was done in October 2009 to reveal household consumption structure in the same residential area. The results show that the air-conditioners are the biggest contributor, which record the averaged electricity consumption of 1,167kWh. Thus, the result shown that air- conditioner consumes much power usage. Therefore, other alternative should be used to achieve thermal comfort for office building at 25 °C [2]

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and residential building at 28 °C to 29 °C [3]. Overall, the ranges to achieve thermal comfort are 25 °C to 29 °C.

1.2 Vertical gardens as evaporative cooler

More recently Davis & Ramirez [4] carried out experimental work with a modified vertical garden module, where they activated it to acclimatise incoming air in one of three methods. Method 1: By passing air in a controlled flow over the foliage of the vertical garden, where the air was to be cooled by the plant transpiration. Method 2: By passing air behind the vertical garden, in the space between the substrate and the surface onto which the garden was attached. This mechanism was to have the air-cooled and humidified through its contact with the humid substrate. Method 3: By sucking air through the vertical garden, where the air was to be cooled in a manner similar to a traditional swamp cooler

It is found that method 1 to not be very effective, due to the air being heated in the glass chamber [4]. Overall the results were found to be promising. The researcher suggested that the most effective manners by which incoming air is climatised were either through method 2 or by method 3 [4]. With that being said, Method 3 [5] was tested which is by flowing air through the vertical garden with a further degree of certainty, by repeating the experimentation of Davis & Ramirez [4] but with the absence of a glass fronting. The results are shown in Figure 1 where the temperature decreased from 31.5 °C to 30 °C which is about 1.5 °C reduction.

It is then followed by experimenting method two which is by forcing air to flow in the space behind the garden where the air is cooled and humidified through its contact with the humid substrate [6]. Table 1 shows the results of the second method which reduced 2.13 °C of the temperature. Overall, this shows the potential of plants in reducing the ambient temperature about 2 °C depending on the surrounding temperature.

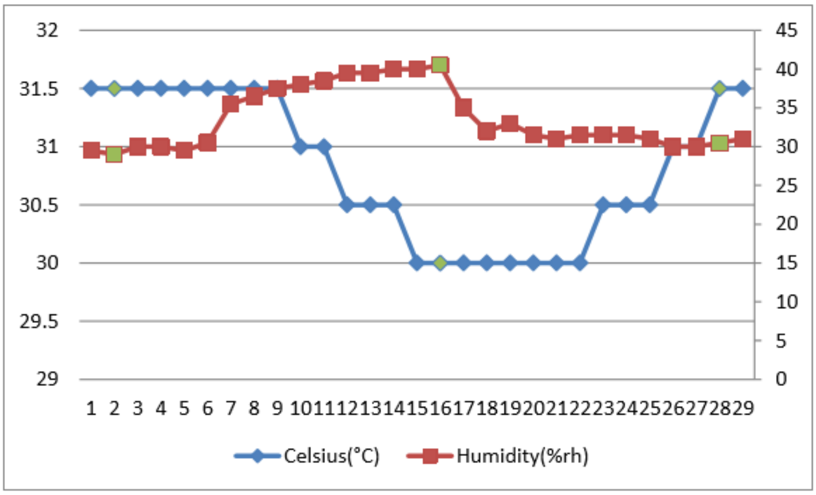

Figure 1: Temperature and humidity

Table 1: Comparison between mathematical model and experimental results

	Mathematical model	Experimental results
T_{in} [°C]	27.50	27.50
T_{out} [°C]	25.81	25.38
ΔT [°C]	**1.69**	**2.13**
RH_{in} [%]	45.07	45.07
RH_{out} [%]	59.99	54.56
ΔRH [%]	**14.92**	**9.49**

2. Experimental

For this project, spider plants are used for transpiration to cool the surrounding air. Spider plants have the ability to reduce formaldehyde [7] and carbon monoxide from the surrounding air. This can act as a passive air purifying device to clean the surrounding air and it is easy and cheap to maintain. Heron's fountain method is applied to reduce the work done by the pump and also reduce the power consumption of the pump [8]. Equation (1) shows the velocity of water exiting the nozzle of the fountain and Equation (2) to obtain volume flow rate, Q.

$$V = \sqrt{2g(h1 - h2)} \quad (1)$$

$$Q=AV \quad (2)$$

The value of h1 and h2 much depend on the diameter of the tube. For h1 = 1.165m, h2 = 0.22m and the tube diameter of 0.0045m constantly all across the system, the flow rate in litre per second is:

Q= 0.273 litre/s

The volume flow rate was obtained assuming that a confined air is uncompressible and neglecting the friction. But for the real velocity of water from the nozzle, the velocity and flow rate will be less than it is given by the value that is calculated. Based on the equation, if bottle the bottom tank is lowered even further, this causes the height difference to increase thus causing the fountain to spray even faster.

Cooling performance test is where the ability of the cooler to reduce the surrounding temperature is tested at a fix area. The experiment is conducted in a small individual room about 9 x 10 square feet. Since the expected difference in temperature is not that great, a temperature and humidity sensor using Arduino programming was used. The following procedures were followed, (a) a measurement was taken of the ambient temperature and humidity levels of the room before operating the thermal comfort device, (b) the ambient measurement of the air temperature was taken again every five minutes for 45 minutes.

The velocity calculated was then used to calculate the volume flow rate using Equation (2), here,
Q = volume flow rate
A = cross section area of the pipe / water flow
V = velocity of the flow

For V= 4.3m/s, Q= (π x 0.0045^2) x 4.3 m/s
Q=2.735x10^{-4} m^3/s

Therefore, the flow rate in litre per second is:

Q= 0.273 litre/s

The above result was obtained assuming that a confined air is uncompressible and neglecting the friction. But for the real velocity of water from the nozzle, the velocity and flow rate will be less than it is given by the value that is calculated. Based on the equation, if bottle the bottom tank is lowered even further, this causes the height difference to increase thus causing the fountain to spray even faster.

3. Results and discussion

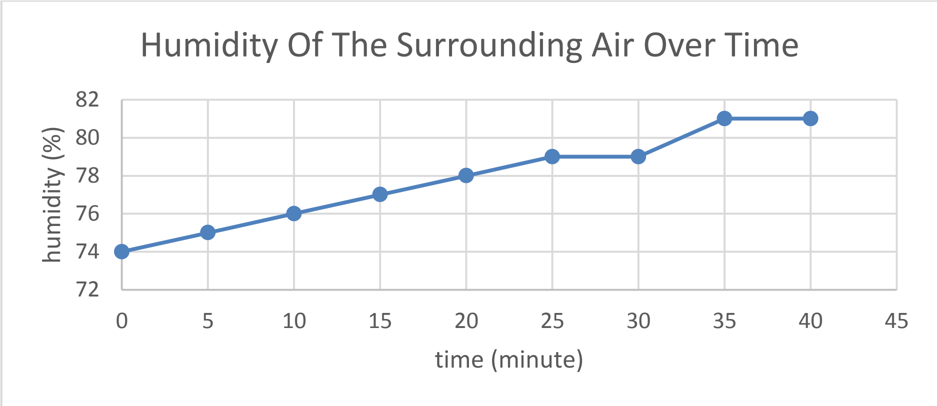

Figure 2: Humidity of the Air over Time

Figure 2 shows the graph of humidity of the surrounding air in the room over time. The humidity of the air was obtained for every 5 minutes interval with a maximum time of 40 minutes. The initial reading of the humidity level was at 74%. From the graph, it was observed that the humidity level increases by 1% every 5 minutes until the time reaches 25 minutes. This increment is mainly due to the evaporation of water at wet cotton and the transpiration of spider plants. This processes release water vapour to the surrounding which increases the humidity level. The reading of the humidity level between 25-30 minutes remains constant. This is maybe due to outside air entering the small room through the window as the window was opened slightly. This causes humidity level to remain constant as the outside air with different humidity level enters the room. The humidity was then increase to 81% by 35 minutes and remain constant through the 40 minutes.

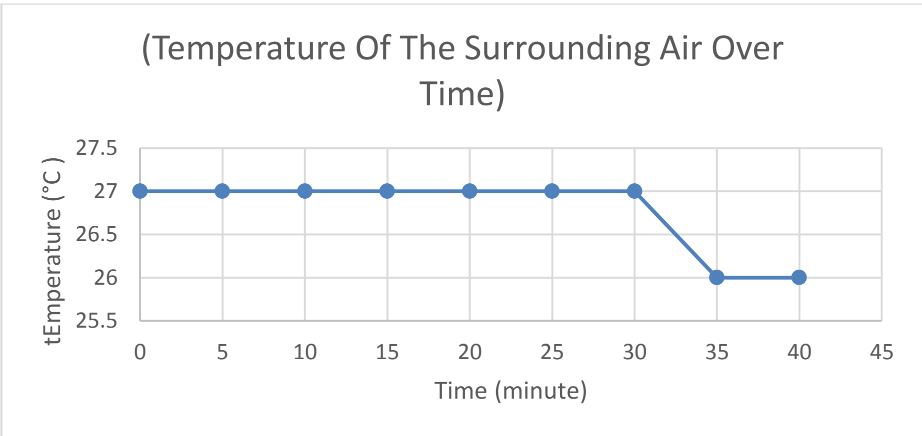

Figure 3: Temperature of the Air over Time

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Figure 3 shows the graph of the temperature of the surrounding air in the small room over time. The initial temperature of the room obtained was 27 °C. The temperature remains constant at 27 °C until the 30 minutes. The temperature then decreases to 26 °C at 35 minutes. This is because as the humidity increases, it decreases the surrounding temperature.

Plants have potential in decreasing the ambient temperature. But the effect of cooling will be opposite as human body constantly try to maintain its internal temperature by evaporating moisture from skin to the atmosphere to cool the body. In humid conditions where surrounding air cannot hold further water vapour, sweat evaporates slowly. As a result, the body heats up. Therefore, in high humidity conditions people tend to sweat more. This explains why it feels so much hotter in high humidity. This clearly shows that the thermal comfort device can operate more effectively in hot climate and when the humidity level of the air is lower. For the solar cooler, solar energy was used as a power source for the device. The solar energy was converted and stored in a 12 volt lead acid battery with a 12 AH current reading. The electricity collected was used to power the loads which are the cooling fan and the water pump. The calculation to determine the maximum operation hours of the device using Equation (3) shown below:

$$I = \frac{P}{V} \tag{3}$$

Current for cooling fan:
I = $\frac{21}{12}$ = 1.75 A

Current for water pump if run continuously:
I = $\frac{3}{12}$ = 0.25 A

Total current = 1.75+0.25 = 2 A

The value of the total current calculated are used to determine the total operating hours using the Equation (4).

$$\text{Operating hours} = \frac{volt\ of\ the\ battery}{total\ current\ of\ load} \tag{4}$$

The calculation shown are for total operating hours of 6 hours. The total time taken to charge the battery are calculated using Equation (5) and Equation (6) shown below:

$$\text{Charge time (hours)}: \frac{amp - hours\ removed\ \ x\ 1.15}{charge\ rate} \tag{5}$$

$$\text{Charge rate}: \frac{wattage\ of\ panel}{voltage\ of\ battery} \tag{6}$$

Calculation are shown below:
Charge rate: $\frac{50W}{12V}$
= 4.166 A
Charge time (hours): $\frac{12\ \ x\ 1.15}{4.166}$
= 3.31 hours

Based on the calculation, it only takes 3.31 hours to fully charge the battery from 0% to 100% capacity. Since solar energy is available everywhere, this contributes much to the people living in rural areas where electrical power source are hardly to obtained.

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4. Conclusion

Particularly in this project, the use of plant as a cooling medium for the thermal comfort device shows potential in reducing the ambient temperature of a room. Not only that, the device can also act as air purifying device as certain plants can purify the air naturally. Based on the results, the thermal comfort device can reduce around 2 °C of the surrounding temperature which achieved the temperature of comfort range of 25-29 °C for residential building.

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