An Experimental Analysis of Direct Evaporative Cooler by Changing its Cooling Pads

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Abstract - *Demand for electric power during peak periods in summer is a vital concern for many utilities in the fast-moving world. From the demand point of view on the grid and cost to the consumer, it is quite wise to install, energy efficient evaporative coolers rather than conventional air conditioners. Evaporative cooling has a great many advantages over other cooling processes. Due to the non-pollution creating environment, it is considered as one of the suitable ways to cool ones workplace or living place because of the fact that it uses fresh air and replaces the air time to time, quite frequently, an hour. Due to recirculation of air, smells and allergens are expelled. It bases on a natural process of air cooled by water; it won't dry out the air, or irritate human skin, eyes, or other external parts of the human body. It allows the doors to be left open for one to sustain the heat of summer. Moreover, evaporative cooling is an inexpensive cooling option which enhances the lifestyle of people. However, evaporative cooling requires abundant water and is efficient when the relative humidity is low.*

Key Words: Evaporative cooling, Cooling Pad, Cooling Efficiency, Coconut Coir and Aspen etc.

1. INTRODUCTION

There is growing demand for space cooling in hot climates as people spend most of their days indoors. To a very large extent, the quality of lives of human beings depends on the quality of their indoor environment. Thermal comfort is defined as the condition of mind that expresses satisfaction with the thermal environment . Therefore, the provision of thermal comfort for the user of buildings is fundamental. The conventional refrigerated-based air conditioning systems are the systems commonly used for providing thermal comfort for occupants of a living space. But in most developing countries of the world, the use of these systems is impeded by the epileptic power supply and the high cost of the systems.

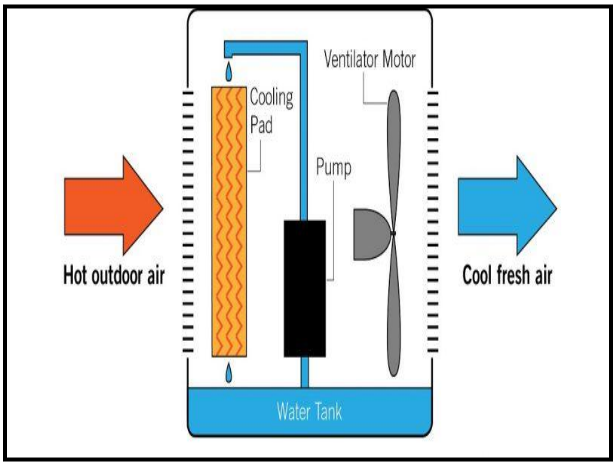

Fig. Direct Evaporative Cooling System

They are relatively expensive for the common man They are not fully utilized in areas where the power supply is epileptic and constantly interrupted They are characterized by poor indoor air quality because of the use of recirculated air .Evaporative coolers are suitable alternative to refrigerated-based air conditioning systems. In this system, the natural effect of evaporation is used to remove the heat from the air of the living space. Unlike the refrigerated-based air conditioning systems, the evaporative coolers have the following advantages: Unlike most refrigerated cooling systems that rely on recycled cooled air with partial fresh air replacement, the evaporative cooler enjoys popularity in the introduction of a continuous supply of freshly cooled outdoor air. These creations of healthy invigorating conditions generate a feeling of relaxed enthusiasm, conducive to improve people concentration and work output. This is due to the naturally cooled, humidified, negatively ionized air which does not dry up nasal passages, eyes or skin, unlike the positively ionized, artificially cooled air from a refrigerated based air conditioning Helps maintain natural humidity levels, which benefits both people and furniture and cut static electricity Does not need an air-tight structure for maximum efficiency, so occupants can open doors and windows The working fluid, water, does not have negative impacts on the environment and it is relatively available and cheap The technology of evaporative cooler is simpler, the cooler costs about 80 per cent less than refrigerated based air conditioner that will cool the same area. The installation costs of evaporative coolers are comparable to conventional air conditioning. Evaporative coolers can be direct, indirect or direct-indirect systems. Apart from the climatic region where the evaporative cooler is to be used, one significant factor that determines the performance of an evaporative cooler is the type of the evaporative cooling pad used.

Different evaporative cooling pads have a different water retention capacity which is attributable to the different structural features of the pad. Therefore, the performance of evaporative coolers to a reasonable degree is hinged on the saturation effectiveness of the evaporative cooling pad material. This Experiment attempts to analyze the performance of coconut coir as media in direct evaporative cooler.

2. LITERATURE REVIEW

Evaporative cooling is a physical phenomenon in which evaporation of a liquid, typically into surrounding air, cools an object or a liquid in contact with it. Evaporative cooling occurs when air, that is not too humid, passes over a wet surface; the faster the rate of evaporation the greater the cooling. There have been various designs over the years. In early Ancient Egyptian times, paintings depicting slaves fanning large, porous clay jars filled with water which is essentially is a very, very early form of evaporative cooling. The first man made coolers consisted of towers that trapped wind and funnelled it past water at the base and into a building. This in turn kept the building cool at the time. (dualheating.com).

In 1800 B.C the new England textiles factory began to use the evaporative cooling systems to cool their mills (www.evaprocool.com). In the 1930's the Beardmore tornado airship engine used to reduce and completely remove the effect of using a radiator which reduces the effect of lag.(coco.cooler.com) Bamboo coolers were constructed with bricks with hessian cloth which were used to wrap the bricks. Also, charcoal coolers were also produced together with the Almirah coolers. Rusten, (1985) described some types of evaporative cooling that was been used in New Delhi, India in which a wetted mat with fan was used to cool a local restaurant. The concept of water-cooling a roof has a long history but it is estimated that less than 60 million square feet of roof have ever been water cooled (Tiwari *et al*., 1992). It was also reported that if only a small amount of water is placed on the roof, the evaporation is highly accelerated as compared to what would be if the roof surface was flooded (Carrasco, 1987).

The researches views are introduced as J.M. Wu, X. Huang, H. Zhang, In this paper Theoretical analysis to the heat and mass transfer between air and water film in a direct evaporative cooler with wet durable honeycomb papers constituting the pad modules is carried out. Y.J. Dai, K. Smith ,The characteristics and the performance of a crossflow evaporative cooler using honeycomb paper as packing material have been studied. Under typical conditions, it can reduce the air temperature by 9oC and increase the humidity ratio by about 50%. The minimum air temperature can be obtained at the length of the air channel to be about 5–10 cm. Zhang Qiang , Liu Zhongbao, Yang Shuang, Ma Qingbo, has described the experimental and theoretical analysis of a TSEC unit is done. The outlet air temperature drop by the two-stage evaporative cooler depends on inlet air wet bulb temperature, secondary air relative humidity and packing thickness of DEC.R. Rawangkula et.al , reports a performance analysis for a new sustainable engineering application to beneficially reuse an abundant agricultural waste, coconut coir (Cocos nucifera), in evaporative cooling pads. Ghassem Heidarinejad et.al , this paper show that under various outdoor conditions, the effectiveness of IEC stage varies over a range of 55–61% and the effectiveness of IEC/DEC unit varies over a range of 108–111%.

J. Khedari et.al , This research was aimed to investigate the feasibility of using dried agricultural waste as desiccant for an open cycle AC system. The natural fibers are used with a intention to replace chemical desiccant such as silica gel etc.. The investigation was limited for Coconut coir (Cocos nucifera) and Durian peels (Durio zibethinus). R. K. Kulkarni and S. P. S. Rajput , This paper analyzes the performance of jute fiber ropes that are used in the form of rope bank as wetted media in evaporative coolers. R. Rawangkul, J. Khedari, J. Hirunlabh and B.Zeghmati , The objective of this study is to develop a moisture adsorption isotherms model of Coconut coir (Cocos nucifera) and to simulate long term performance of this material as desiccant under Bangkok ambient conditions. It is observed that Young coconut coir reveals the average moisture adsorption capacity is about 26% dry basis at the average air relative humidity and temperature of about 73% and 28.6oC, respectively. The maximum moisture adsorption capacity is 37% when air relative humidity is 80%. After referring above researches we can conclude that the best and optimize air cooler can be developed using the evaporative media.

a)Aspen Wood, b) Coconut Coir.

3. PRINCIPLES OF EVAPORATIVE COOLING

The rudimentary basis for understanding any air conditioning, dehumidification and evaporative cooling is psychometrics. Psychrometry consists of the interactions between heat, moisture and air. It is basically the study of air-water mixtures and is an essential foundation for understanding, how to change air from one condition to another. As air temperature rises, its capacity to hold moisture rises also; and warmer air becomes less dense. This makes moisture a very influential factor for heat gain, both for comfort and in calculations. The knowledge of systems consisting of dry air and water vapor is essential for the design and analysis of air conditioning devices, cooling towers, and industrial processes requiring close control of the vapor content in air. Air moisture and heat interactions are rather complex; fortunately, these interactions can be combined in a single chart (see figure below). However before explaining the details of how to use the chart, some terms, definitions, and principles used in the study of systems consisting of dry air and water must be introduced.

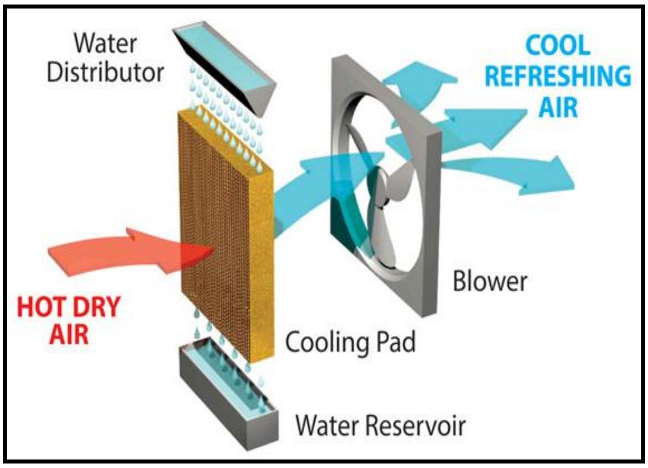

Fig. Basic Principle of Evaporative Cooling

3.1 Dry Bulb Temperature (DBT): The Dry Bulb Temperature refers to the ambient air temperature measured using a normal thermometer freely exposed to the air but shielded from radiation and moisture. It is called "Dry Bulb" because the air temperature is Indicated by a thermometer not affected by the moisture of the air.

The dry bulb temperature is an indicator of heat content of the air. As the DB temperature increases, the capacity of moisture the airspace will hold also increases. The dry bulb temperature is usually given in degrees Celsius (ºC) or degrees Fahrenheit (ºF). The SI unit is Kelvin (K). Zero Kelvin equals to -273oC.

3.2 Wet Bulb Temperature: The Wet Bulb temperature is the temperature measured by using a thermometer whose glass bulb is covered by a wet wick/cloth. The wet bulb temperature is indicator of moisture content of air. Wet bulb temperature is very useful in evaporating cooling processes as the difference between the dry bulb and wet bulb temperature is a measure of the cooling efficiency. At 100% relative humidity, the wet bulb temperature equals dry bulb temperature.

3.3 Humidity: The term humidity describes the quantity of water vapor in air. If the air holds 50% of its capacity, the humidity would be 50%. If the humidity is low, then the capacity to hold more water is higher, and a greater amount of evaporation takes place. It can be expressed as an absolute, specific or a relative value.

3.4 Absolute humidity: Absolute humidity is the actual mass of water vapor in the air water vapor mixture. Absolute humidity may be expressed in pounds of water vapor (lbs).

3.5 Specific humidity or (humidity ratio) is the ratio between the actual mass of water vapor present in moist air - to the mass of the dry air. The humidity ratio is very useful in evaporative cooling because it provides the measure of the amount of moisture absorbed by the air stream and is useful in determining the spray water requirements. Specific

Humidity is normally expressed in grains of water vapor /lb of dry air and may also be expressed in the units of pounds of water vapor/lb of dry air or grams of water vapor /kg of dry air.

3.6 Relative humidity: Relative Humidity or RH is the actual amount of moisture in the air compared to the total or maximum moisture the air can hold at a given temperature.

When air has 50 percent relative humidity (RH), we say it is 50 percent saturated (the terms are numerically so close that we use them interchangeably). Obviously, as air approaches 100 percent saturation, it can take on less and less water until at 100 percent RH, the air cannot hold more water. Relative humidity is determined by comparing the "wet-bulb" and "dry-bulb" temperature readings. Dry bulb and wet bulb temperatures are taken simultaneously and then plotted on a psychrometric chart. Relative humidity is determined by the value at the intersection of two temperature lines.

3.7 Dewpoint: The Dew Point is the temperature at which water vapor starts to condense out of the air and becomes completely saturated. Above this temperature the moisture will stay in the air. The dew point temperature is an indicator of the actual amount of moisture in air. The dew-point temperature is expressed in degrees and like humidity ratio; it represents an absolute measure of the moisture in the air at a constant pressure. If the dew-point temperature is close to the air temperature, the relative humidity is high, and if the dew point is well below the air temperature, the relative humidity is low.

3.8 Grains of moisture: Term used to express the weight of moisture per pound of air (14 cubic feet). 7000 grains is the most that can be held in one pound of air. Since water weighs 8.34 pounds per US gallon and since there are 8 pints in one gallon, 7000 grains is equal to about 1 pint of water. Grains of moisture per pound of air are most often referred to as "humidity ratio". 50 grains of moisture at 100ºF equals 12% relative humidity and 70ºF wet bulb at sea level.

3.9 Sensible Heat: The heat used to change the temperature of the air. Sensible heat will always cause a change in the temperature of the substance.

3.10 Latent heat: Latent heat is the heat energy involved in the phase change of water. The heat will only change the structure or phase of the material without change to temperature.

4. EXPERIMENTATION

The experimental test rig of low cost desert cooler available in market is tested in laboratory at various different conditions. The desert cooler with aspen wood pad and with coconut coir pad is tested separately. The aspen wood pads are tested as per standards available in the market but coconut coir pads of different thicknesses are made for testing purpose .The pads thickness varies from 2cm to 7cm. The report shows the theoretical Analysis of Heat and Mass Transfer in Direct Evaporative Cooler. The numerical relation between Cooling efficiency and the geometric parameters of the cooling pad indicates that the dimensions of the cooling pads can affect the cooling performance. The paper shows, the simplified relation between cooling efficiency and cooling pad thickness.

First, we will make the assumptions to develop The Analytical Model, to simplify the equation; we will neglect the least affecting factors.

The assumptions are as follows:

- Cooling pad material is wetted uniformly and fully.
- Convective heat transfer coefficient and mass transfer coefficient of moist air on the surface of water film are constant.
- Heat flux transferred from surrounding is neglected.
- Water-air interface temperature is assumed to be uniform and constant.
- Thermal properties of water and air are constant.
- Air temperature changes only in the flow direction.

According to Experimental setup, the correlation between cooling efficiency can be expressed as follows:

Cooling or saturation efficiency (η),

$$\eta = [(t_1 - t_2)/(t_1 - t_s)] \times 100$$

Where, t_1 = Inlet dry bulb temperature

t_2 = Outlet dry bulb temperature

t_s= Inlet wet bulb temperature

As per the equation, the efficiency can be directly expressed in term of Geometrical properties of cooling media. To find the outlet properties of cooling media we can compare this correlation with classical saturation efficiency equation. The classical Saturation efficiency equation is as follows:

If we know the geometric properties of the rigid cooling media, the using first equation we can find the cooling efficiency of the evaporative cooler. Once we have a cooling efficiency of the cooling system and know Inlet properties of air (t1 & ts), then by comparing efficiency in the second equation, we can easily find outlet air dry bulb temperature. Using above method, we can easily find the predicted values for outlet dry bulb temperature for the Rigid media evaporative cooling system.

Fig. 5 Test rig of Evaporative cooler

Setup Table:

Parameters	Summer
Room upto	10×11 ft^2
Blower/Fan	Fan
Fan diameter	20 cm
Speed regulator	constant speeds
Supply	230V/50HZ
Tank capacity	--------
Cooling media	Aspen, coconut coir etc.
Area of pad	cm2
Air velocity	In March and April Months

1} Aspen Fiber

Time	Initial temp. (t_1)	Final temp. (t_2)	Initial humidity (w_1) %	Final humidity (w_2) %	WBT (T_s)
Morning	30.9	26.2	36	80	20
Afternoon	30.8	25.2	46	77	21.7
Night	31.1	24.2	37	81	21.2

Table Aspen Fiber

2} Coconut Coir Fiber

Time	Initial temp. (t_1)	Final temp. (t_2)	Initial humidity (w_1) %	Final humidity (w_2) %	WBT (T_s)
Morning	32.1	25.6	42	74	22
Afternoon	35.2	27.4	37	62	23.2
Night	33.3	28.7	35	70	21.5

Table Coconut Coir Fiber

3} Combination of two Different Pad

Time	Initial temp. (t_1)	Final temp. (t_2)	Initial humidity (w_1) %	Final humidity (w_2) %	WBT (T_s)
Morning	29.9	24.9	51	89	22.1
Afternoon	33.5	26.8	37	80	22.2
Night	32.8	25.9	44	86	23

Table combination of two pad

Table Experimental Analysis Of Evaporative Cooler

Sr. No	Type of cooling pad (material)	Thick ness (cm)	Inlet DBT (^{0}C)	Initial Humidity (%)	Outlet DBT (^{0}C)	Final Humidity (%)
1	Aspen wood wool pad	2	30.93	39.66	25.2	79.33
2	Coconut Coir fiber	2	33.53	38	27.23	68
3	Combination of 2 different pads	2	32.06	44	25.86	85

5. ANALYTICAL CALCULATIONS

An experimental analysis of a direct evaporative cooler is done by varying material and thicknesses of cooling pads. Readings of various terms related to performance of direct evaporative cooler are taken which are given in the previous chapter. Based on these readings some calculations need to be done for analysing the performance of a fabricated cooler. These calculations include calculation of various terms such as cooling or saturation efficiency, temperature drop achievable, achievable temperature and percentage increase in humidity which are given below.

1)Cooling or saturation efficiency (η),

$\eta = [(t_1 - t_2)/ (t_1 - t_s)] \times 100$

Where, t_1 = Inlet dry bulb temperature

t_2 = Outlet dry bulb temperature

t_s = Inlet wet bulb temperature

2)Temperature drop achievable,

Temperature drop achievable = $(t_1 - t_s) \times \eta$

Where, t_1 = Inlet dry bulb temperature

t_s = Inlet wet bulb temperature

η = Cooling efficiency

3)Achievable temperature,

Achievable temperature = Inlet dry bulb temperature (t_1) – Temperature drop achievable

4) Percentage increase in humidity,

Increase in humidity = Final humidity – Initial humidity

These above four terms are calculated for each type of cooling pads considered in the previous chapter separately, which are given below.

I) Considering Aspen wood wool pad

For 2cm thickness,

t_1 = Inlet dry bulb temperature = 30.93^{0}C

t_2 = Outlet dry bulb temperature = 25.2^{0}C

Initial humidity = 39.66%

Final humidity =79.33%

From psychometric chart,

t_s = Inlet wet bulb temperature = 20.9^{0}C

Cooling or saturation efficiency (η),

$\eta = [(t_1 - t_2)/ (t_1 - t_s)] \times 100$

$\eta = [(30.93 - 25.2)/ (30.93 - 20.9)] \times 100$

$\eta = 57.13\%$

Temperature drop achievable = $(t_1 - t_s) \times \eta$

$= (30.93 - 20.9) \times 57.13\%$

Temperature drop achievable = 5.73^{0}C

Achievable temperature = Inlet dry bulb temperature (t_1) – Temperature drop achievable

= 30.93^{0}C – 5.73^{0}C

Achievable temperature = 25.2^{0}C

Increase in humidity = Final humidity – Initial humidity

= 79.33 – 39.66

Increase in humidity= 39.67%

II) Considering Coconut fiber pad

For 2cm thickness,

t_1 = Inlet dry bulb temperature = 33.53^{0}C

t_2 = Outlet dry bulb temperature = 27.23^{0}C

Initial humidity = 38%

Final humidity = 68%

From psychometric chart,

t_s = Inlet wet bulb temperature = 22.23^{0}C

Cooling or saturation efficiency (η),

$\eta = [(t_1 - t_2)/ (t_1 - t_s)] \times 100$

$\eta = [(33.53 - 27.23)/ (33.53 - 22.23)] \times 100$

$\eta = 55.75\%$

Temperature drop achievable = $(t_1 - t_s) \times \eta$

= $(33.53 - 22.23) \times 55.75\%$

Temperature drop achievable = 6.2^0C

Achievable temperature = Inlet dry bulb temperature (t_1) – Temperature drop achievable

= $33.53^0C - 6.2^0C$

Achievable temperature = 27.33^0C

Increase in humidity = Final humidity – Initial humidity

= 68 – 33.53

Increase in humidity = 34.47%

III) Considering combination of two different types of pad

Aspen wood wool pad = 2cm thickness,

Coconut fiber pad = 2cm thickness,

t_1 = Inlet dry bulb temperature = 32.06^0C

t_2 = Outlet dry bulb temperature = 25.86^0C

Initial humidity = 44%

Final humidity = 85%

From psychometric chart,

t_s = Inlet wet bulb temperature = 22.43^0C

Cooling or saturation efficiency (η),

$\eta = [(t_1 - t_2)/ (t_1 - t_s)] \times 100$

$\eta = [(32.06 - 25.86)/ (32.06 - 22.43)] \times 100$

$\eta = 64.38\ \%$

Temperature drop achievable = $(t_1 - t_s) \times \eta$

= $(32.06 - 22.43) \times 64.38\%$

Temperature drop achievable = 6.1^0C

Achievable temperature = Inlet dry bulb temperature (t_1) – Temperature drop achievable

= $32.06^0C - 6.1^0C$

Achievable temperature = 25.96^0C

Increase in humidity = Final humidity – Initial humidity

= 85 – 44

Increase in humidity = 41%

6. RESULT AND DISCUSSIONS

An experimental analysis of a direct evaporative cooler by varying material an of cooling pads is done and following results are obtained from the analysis.

Table 12.1- Cooling or saturation efficiency

Sr. No.	Type of cooling pad (material)	Cooling efficiency (%)
1	Aspen wood wool pad	57.13
2	Coconut fiber pad	55.7
3	Combination of two Different Pad	64.38

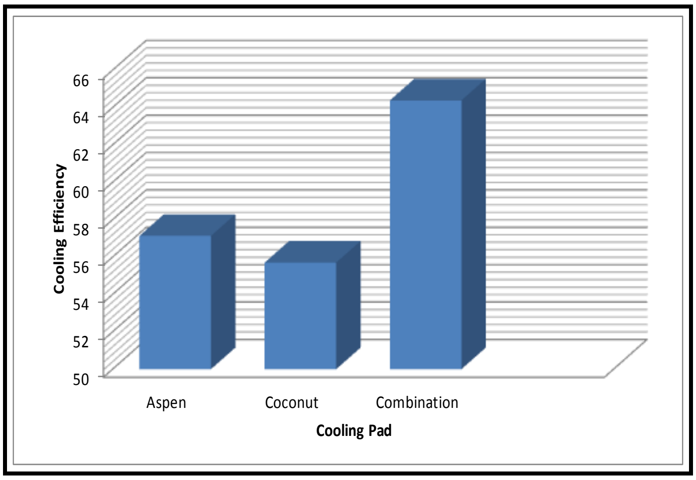

Fig . Graph of cooling efficiency based on above table

Sr no.	Type of cooling pad (material)	Increase in Humidity (%)
1	Aspen wood wool pad	39.67
2	Coconut fiber pad	34.47
3	Combination of two Different Pad	41

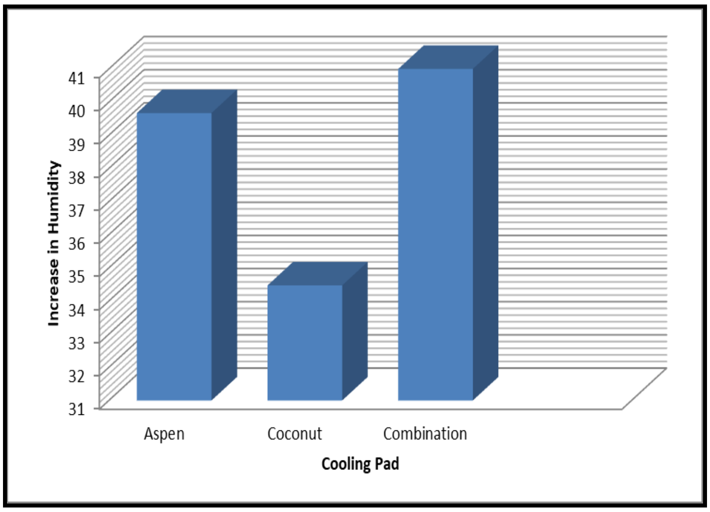

Fig. Graph showing percentage increase in humidity based on above table

Sr. No.	Type of cooling pad (material)	Temperature drop achievable (⁰C)
1	Aspen wood wool pad	5.73
2	Coconut fiber pad	6.2
3	Combination of two Different Pad	6.1

Table Temperature drop achievable

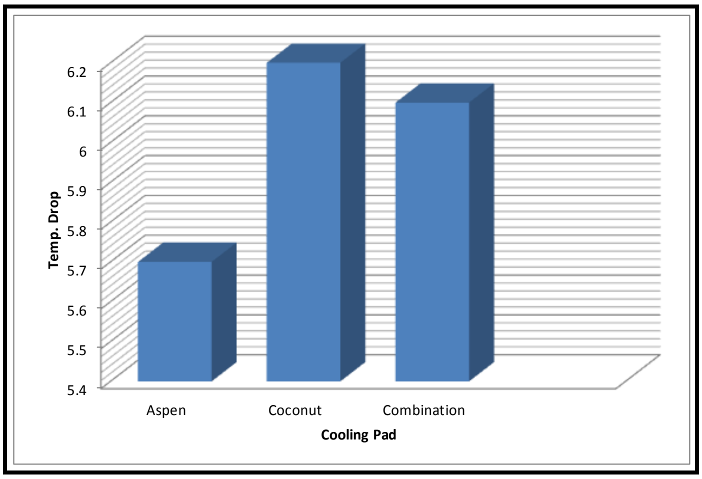

Fig. Graph show temp. drop achievable based on above table

7. APPLICATIONS

1. Air conditioning

The main application of evaporative cooling is the air-conditioning of premises in hot and arid regions. Humidification of excessively dry air improves comfort to an extent: when it is hot, the human body's thermal regulation depends precisely on evaporative cooling as perspiration is the evaporation of water through pores and this natural regulation process is hindered when the air is too humid. It is generally considered that human thermal comfort conditions are met when the temperature is between 20 and 27°C and relative humidity between 30 and 65-70%.However, the definition of the conditions of temperature and humidity considered "comfortable" for the human body depends at least to an extent on individual perception.

2. Storage of perishable foodstuffs

In hot countries, evaporative cooling cannot achieve the temperatures recommended for products of animal origin or for most of the products of vegetal origin. However, in some cases, it may allow a significant slowdown of the deterioration process of tropical fruit and vegetables, thus making possible an appreciable gain in terms of shelf life and marketing periods. The increase in relative humidity reduces the wilting and weight loss by evapotranspiration of fruit and vegetables, but an excess of relative humidity encourages the proliferation of unwanted organisms, including fungi (botrytis, penicillium...) resulting in the deterioration of the products, or even in the production of bio-toxins. For the preservation of fruit and vegetables, recommended humidity is generally 85-95%. The risk of corrosion of metal parts is also to be taken into consideration.

3. Pre-cooling

When evaporative cooling does not achieve the desired temperatures, in some cases, it can be used for pre-cooling operations, so as to reduce the energy consumption of conventional devices used to achieve the temperatures required, as well as the sizing of these devices, thus allowing for lower operation and investment costs.

8.ADVANTAGES AND DISADVANTAGES

Based on available information of direct evaporative cooling system different advantages and disadvantages can be summarized as follows:

8.1 Advantages:

The main advantages of evaporative coolers are their low cost and high effectiveness.

- ➢ Permitting a wide range of applications and versatility in the buildings, dwellings, commercial and industrial sectors.
- ➢ Direct evaporative devices act like filters, removing dust particles in air.
- ➢ It requires no special skill to operate and therefore is most suitable for rural application.
- ➢ It can be made from locally available materials.
- ➢ Highly efficient evaporative cooling systems that can reduce energy use by 70%.
- ➢ Less expensive to install and operate.
- ➢ It can be easily made and maintained.

8.2 Disadvantages:

- ➢ The water consumption associated to the operation of these systems, which is ascarce resource in dry and hot climates, where these systems best work.
- ➢ Evaporative cooling system requires a constant water supply to wet the pads. Therefore, need to be watered daily.
- ➢ Space is required at outside the home.

- Water high in mineral content leave mineral deposits on the pads and interior of the cooler gets damaged.[2,10]

- DEC is only suitable for dry and hot climates. In moist conditions, the relative humidity can reach as high as 80%, such a high humidity is not suitable for direct supply into buildings, because it may cause warping, rusting, and mildew of susceptible materials.

9. CONCLUSION

An experimental analysis of direct evaporative cooler by varying materials of cooling pads is performed. The cooling pads of materials such as Aspen wood wool and coconut fibers are used in the model of cooler for doing the analysis. Efficiency of combination of two different cooling pad (Aspen & Coconut) is more than that of separate aspen and coconut cooling pad. Humidity of coconut cooling pad is less than as compare to combination of two different cooling pad (Aspen & Coconut) and separate aspen cooling pad. Water consumption of coconut cooling pad is less as compare to combination of two different cooling pad (Aspen & Coconut) and separate aspen cooling pad.

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