# Design and Development of Low Cost Mud Pot Air Coolers

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**Abstract –** *Evaporative cooling is a heat and mass transfer process, that uses water evaporation for air cooling, in which large amount of heat is transferred from air to water, and consequently the air temperature decreases. The project deals with the* ***design and development of low cost mud pot air coolers****, which is a type of Active direct evaporative cooling system, with good efficiency. The aim is to achieve better Cooling and make the product easily available to different sections of society at lower cost, as the materials used in the product are* ***mud pots, aspen wood wool or coconut fiber made evaporative cooling pads****. A theoretical model was developed on python to simulate the results related to the effectiveness of the design. The product is very low cost as compared to the conventional room coolers, because of use of mud pot and cost of manufacturing of mud pot is low at the same time, if this product is made available on large scale can create lot of job opportunities for regions like rural India.*

***Key Words***: mud pot, evaporative cooling pads, python, simulation, Evaporative cooling, effectiveness, air coolers

## 1.INTRODUCTION

Energy demand worldwide for buildings cooling has increased sharply in the last few decades, which has raised concerns over depletion of energy resources and contributing to global warming. Current energy demand estimates stand at between 40 and 50% of total primary power consumption. In hot climate countries, the highest share of building energy use is mainly due to space air conditioning using traditional HVAC systems. For example, in the Middle East, it accounts for 70% of building energy consumption and approximately 30% of total consumption. Currently, mechanical vapour compression coolers (MVC) are commercially dominant despite their intensive energy use and low performance in hot climate. In contrast, evaporative cooling systems are more environmentally friendly as they consume less energy and their performance improves as air temperature increases and humidity decreases. Evaporative cooling is a heat and mass transfer process.

That uses water evaporation for air cooling, in which large amount of heat is transferred from air to water, and consequently the air temperature decreases. Evaporative coolers could be classified into:

1) Direct evaporative coolers, in which the working fluids (water and air) are in direct contact.

2) Indirect evaporative coolers, where a surface/plate separates between the working fluids.

3) Combined system of direct and indirect evaporative coolers.

The current Research deals with the design and development of low cost, Easy to manufacture mud pot air coolers which is a direct evaporative cooling technology. Direct evaporative cooling technology is the oldest and the simplest type of evaporative cooling in which the outdoor air is brought into direct contact with water, i.e. cooling the air by converting sensible heat to latent heat. Ingenious techniques were used thousands of years ago by ancient civilizations in variety of configurations, some of it by using earthenware jar water contained, wetted pads/canvas located in the passages of the air. Direct Evaporative Cooling systems (DEC) could be divided into: Active DECs which are electrically powered to operate and Passive DECs that are naturally operated systems with zero power consumption. 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 rooms as it may cause uncomfortable environment. A typical direct evaporative cooler comprises of evaporative media (wettable and porous Pads), fan blows air through the wetted medium, water tank, recirculation pump and water distribution system, as illustrated schematically in Fig. 1.2. [1] The direct evaporative cooling is an adiabatic cooling process, i.e. the total enthalpy of the air is constant throughout the process the water absorbs the sensible heat from the supply air and The conventional DEC uses electricity to run, fan, and pump and also there is a need of good water distribution system for effective cooling of air.

Evaporative coolers find its vast use in various places such as data centres, office buildings, ware houses, hospitals, laboratories and residential houses. Locations such as data centres house hundreds of computers and servers in addition to complex network systems, all of this generate heat, the evaporative coolers are essential to keep data centres cool, maintaining a proper humidity. Office environments, can be very difficult to keep cool and comfortable without proper humidity control. Using an evaporative cooler can assist with keeping temperatures in check while also cycling in fresh outside air, which is essential to employee wellness and productivity. Some goods, such as woods and musical instruments, can suffer from warping and damage in hot conditions. The installation of evaporative cooler can help to mitigate this risk. Airborne infection control is of critical importance to any healthcare environment, as in minimizing the risk of cross contamination, this can't be achieved without controlling the amount of air moisture content, which is influenced by current temperature, here evaporative coolers can be beneficial. Other applications of evaporative coolers are, commercial kitchens, large factories, retail centres, indoor

sports facilities, green houses, restaurants and guest houses as well as mining operations.
Many companies and small manufacturers are making different kind of DEC or swamp coolers, which are made of plastics, steel, the problem with steel body coolers is that they get rusted easily if the humidity content of the room increases, hence plastic type of air coolers are generally preferred.
The current project deals with design and development of such swamp coolers working on the principle of direct evaporative cooling technology which is easy to manufacture. The main purpose of the project is to use waste materials and eco-friendly technology which is need of the hour. The design in itself is unique and the product is quite efficient in cooling in hot regions, especially in summer season which is very much dry. This product if manufactured on large scale can be used by various segments of society including the poor people. There is a need of using eco-friendly solutions to reduce cost of production, to create jobs for traditional Indian workers, to reduce the energy input, to reduce overall maintenance cost.
In conventional DEC when warm, dry (unsaturated) air is pulled through a water soaked pad, water is evaporated and is absorbed as water vapour into the air. The air is cooled in the process and the humidity is increased. We have tried to change the design of the conventional model hence eliminating the use of water soaked pads, pumps, pipes.

The current modified model is quite simple and easy to study. This model consists of an AC fan which is installed on the top unlike the conventional models. In the design of the model various factors were considered which are both scientific and economic such as humidity, wet bulb temperature, dry bulb temperature, Air flow, porosity of material containing water etc. The study involve in analysis of these factors is psychometry. Psychometry 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 vapour is essential for the design and analysis of air conditioning devices, cooling towers, and industrial processes, requiring close control of the vapour content in air. Air moisture and heat interactions are rather complex; fortunately, these interactions can be combined in a single chart known as Psychrometric chart.
In this project we have used various equipment and tools such as anemometer to find the air flow or discharge velocity. The wet bulb and dry bulb thermometer to observe the temperature of discharge air, psychrometric chart to calculate humidity, various CAD tools to design the actual model.

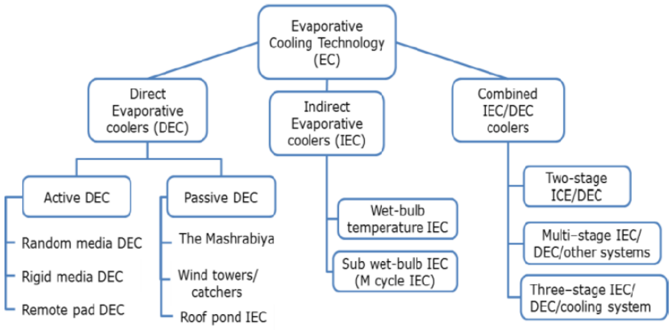


Fig- 1.1 Classification of Evaporative cooling technology [1]

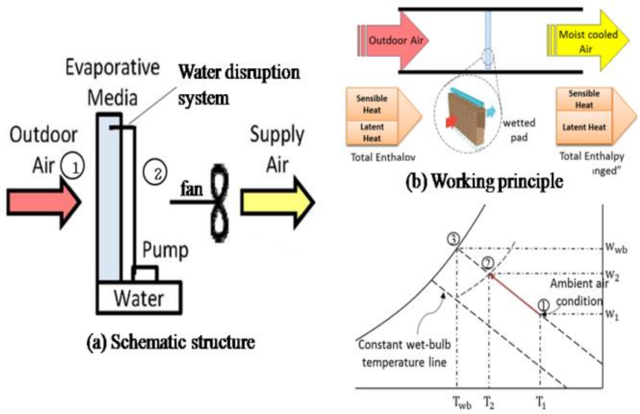


Fig-1.2 (a) Schematic Diagram [1]
(b) Working

## 1.1 Literature review

The new model developed is very much cheap than the conventional air coolers and also very much energy efficient as the use of many systems such as water distribution system, pump, pads has been completely abolished and at the same time the ancient mud pots are used to keep the water in the container cool to increase the rate of evaporation hence to lower the temperature of air exiting the cooler. Various researchers have published research papers on Direct Evaporative coolers and indirect evaporative coolers. The basic idea of swamp coolers is the evaporation rate, the higher the evaporation rate, the better will be the cooling of a swamp cooler. Many researches have been conducted that provide the results that the performance of the swamp coolers depends on the ambient temperature, the material of the cooling medium, velocity of the air, area for evaporation. Many materials are also used for developing of the swamp pads, which can be random media pads, rigid pads which have their own advantages and disadvantages as stated below: [2]

Table-2.1 Evaporative Media and features [2]

| System type | Evaporative media | Effectiveness | Features |
|---|---|---|---|
| Random media | Excelsior or plastic fiber/foam supported by plastic frame. | >80% | Low effectiveness Short life-time. Hard to clean. |
| Rigid media | Blocks of corrugated materials: Cellulose, plastic, fiberglass. | 75-95% | High initial cost. Longer life-time. Cleaner air. |
| Remote pad | Random or rigid Pads mounted on wall or roof of building | 75-95% | Higher power consumption Bacteria growth |


Fig- 2.1 Evaporative media and its properties [2]

All kind of pads used have either disadvantage of bacterial growth, difficulty in cleaning or high cost of investment. All kind of conventional direct evaporative coolers also make use of pump and efficient water distribution system, which is in itself a complicated task to assemble and energy consuming process. Various materials are used to manufacture the coolers such as steel, plastic etc. which make the cost of the product high.

There are various design procedures involved for selecting the right fan for continuous supply of air and taking various heat loads into consideration. Theoretical analysis on evaporative cooling is essential for revealing the heat and mass transfer laws in evaporative cooling process as well as for predicting the process outputs under various working conditions.

A number of studies were conducted on numerical simulation of heat and mass transfer of DEC. Zhang and Chen [3] analysed the heat and mass transport processes in DEC and developed a simplified physical model for the DEC, in which the process air was forced to flow over a wet plate with simultaneous heat and mass transfer. Qian et al [4] established a neutral network model to predict the air handling performance of DEC under various working conditions. The direct cooling technology using water evaporation is widely used for environmental control in agricultural buildings. Khandelwal [5] uses a regenerative evaporative cooling for energy saving opportunity in buildings. The results revealed that evaporative cooling has great potential to save energy up to 15.79%, where simple evaporative cooling has potential to save energy is up to 12.05%. The room temperature range got in between 22 to 26-degree C. El-Awad [6] has studied the solar powered winter air conditioning system using evaporative coolers. In this system solar heat is used to preheat the water. Theoretical model is developed for room of size 3×3×3m3 volumes, and it consumes energy around 0.1KW.

Various researches have been conducted on the cooling media as well, He et al. [7] studied film media used for evaporative pre-cooling of air. The cooling efficiencies of the cellulose media 43% to 90% while PVC media are 8% to 65%. Lee and Lee [8] has been fabricated a regenerative evaporative cooler and tested. To improve the cooling performance, the water flow rate needs to be minimized as far as the even distribution of the evaporative water is secured. At the inlet condition of 32 °C and 50% RH, the outlet temperature was measured at 22 °C which is well below the inlet wet-bulb temperature of 23.7 °C. Xuan et al. [9] first introduced the working principles and thermodynamic characteristics of different types of evaporative cooling, including direct, indirect and semi-indirect evaporative cooling. Fouad [10] discussed heat and mass transfer, process in direct evaporative cooler. The predicted results show validity of simple mathematical model to design the direct evaporative cooler, and that the direct evaporative cooler with high performance pad material may be well applied for air conditioning systems. Kulkarni and Rajput [11] made a theoretical performance analysis of direct evaporative cooling. The results of the analysis showed that the aspen fibre material had the highest efficiency while the rigid cellulose material had the lowest efficiency. Kachhwaha and Prabhakar [12] presented simple and efficient methodology to design a house hold desert cooler, predict the performance of evaporative medium and determined pad thickness and height for achieving maximum cooling. Dai and Sumathy[13] theoretically investigated a cross-flow direct evaporative cooler, in which the wet durable honeycomb paper constituted as the pad material, and the air channels formed by alternate layers of two kinds of papers with different wave angles were regarded as parallel plate channels with constant spacing.

Ndukwu Macmanus Chinenye [14], developed a clay evaporative cooler for the purpose of preservation of fruits and vegetables at a lower temperature and also to study the physical parameters such as cooling efficiency, cooling capacity, etc. in the system. The results showed that the evaporative cooler reduces the temperature up to 10-degree C and increases the relative humidity of incoming air for the storage chamber. The evaporative cooler was able to preserve freshly harvested tomatoes for about 19 days. It is observed that clay is a material which helps in evaporative cooling and has shown proven results and hence can be used as a vital element in the air cooling system. A recent paper published in 2014 by Parsuraman Selvam[15] of IIT madras talked about the use of mud pot in air coolers. The modified air cooler cum storage system developed is a type of conventional air cooler which is used for providing room cooling as well refrigeration systems. The system consists of a lower tank which is a mud pot whose outer periphery is filled by sand slurry. The lower tank and the slurry are held by a larger mud pot, i.e., a pot-in-pot system. The lower tank is filled with water and it is connected to the upper tray through a pump. The water in the upper tray is passed through a cooling pad which is used for absorbing the water. A fan is fixed next to the cooling pad and is followed by a vent system. The tray also has another port which is connected to the cold storage box. On running the system for 5 hours, the temperature of a 960 cubic feet room gets reduced by 12-degree C and the temperature of the cold storage box gets reduced by 11-degree C and reaches 24-degree C, hence providing the right temperature for storage of perishable items. A history of innovation and research on evaporative cooling technology is given in table-1.3. [21]

Generally, the conventional air cooler manufactured make use of evaporative media in large amount and that make the size of the coolers quite big also the maintenance cost become high due to these evaporative media, the water holding device for these coolers is generally made of plastics or steel and mud pot use is not so much promoted, the assembly of water distribution system consisting of pump and pipes is tedious and it also increases the cost of product. Also the formation of aerosol takes place when air velocity increases by 3m/s, which is a drawback in conventional air coolers which limit the cooling efficiency.

The main aim of our project to make a unique design of the DEC with the use of mud pot to keep water inside cool to increase evaporation rate and to reduce the cost of manufacturing, to create job for traditional workers if produced on large scale, to reduce energy input by eliminating the use of pump and water distribution system, this also reduces the wastage of water and to increase the evaporation efficiency by increasing the air velocity and reduce formation of aerosol.

The purpose of selecting the project was to create innovation by switching to eco-friendly solutions. Conventional air cooling technologies make use of CFCs which are released in the atmosphere, and these are also responsible for polluting the environment. Also various resources such as plastics are used in manufacturing of ACs which in itself responsible in polluting the environment. Mud pots are eco-friendly, easy to make alternative to store water for DEC and their efficiency also increases with increase in ambient temperature. Hence, this research project will surely create an impact in the field of air cooling technologies.

Various other research papers and online websites were referred to understand the concept of surface molecular evaporation used in the model. According to Tibor Poósa, Evelin Varjua[16] research paper on "Dimensionless evaporation rate from free water surface at tubular artificial flow" the surface evaporation rate of water is very complex and depends on various factors such as the temperature of water, air. The relative and absolute humidity According to them the surface evaporation when temperature of water surface is much less than the air temperature is governed by conduction and convection and when the temperature of water surface is equal to the temperature of air, the evaporation rate is dependent on the humidity ratio of air and humidity ratio of saturated air at the same temperature. According to the other sources the surface evaporation is dependent on the difference of relative humidity difference of air and saturated air at the water surface temperature.

## 1.2 Design and Development

The project deals with the **design and development of low cost mud pot air coolers**, which is a type of *Active direct evaporative cooling system*, with better efficiency. The aim is to achieve better Cooling and make the product easily available to different sections of society at lower cost, as the materials used in the product are **mud pots, aspen wood wool or coconut fiber made evaporative cooling pads**. The prototype developed is of 60-70 cm height and uses a 100 cfm fan (4 inch) with air throwing capacity of around 5 m/s, And study is done for cfm between 2.5 and 3.5 m/s velocity The product is very low cost as compared to the conventional room coolers, because of use of mud pot and cost of manufacturing of mud pot is low at the same time, if this product is made available on large scale can create lot of job opportunities for rural India. The purpose behind using the mud pot is to reduce cost and increase efficiency during very hot temperatures when coolers are kept outside. (Desert coolers), as the efficiency of cooling of air reduces if temperature of water increases very much. The design of the product is very unique and occupies less space. The fan is fitted on the top unlike in conventional air coolers which have fan in front, putting fan on top helped to reduce the formation of aerosol (mixture of air and water), which is quite common in conventional air coolers. *(Note- the aerosol formation takes place when air with more than 3m/s of speed move over particles of water)*. **The amount of cooling media used in the product prototype is very less (4 inch diameter and 2 cm thickness), the cost of product is reduced drastically by reducing the amount of cooling pad and using the concept of surface (pool type) evaporation which is not commonly used in evaporative coolers**. The design of the product is developed on the CAD software and various research papers were studied to fetch better results based on experiments, computer program is also developed to ease the calculations involved while designing the product. The product is very much efficient in cooling, and the efficiency for various cfm fan is also presented in this paper. The efficiency achieved is better than conventional air coolers, which generally have efficiency in range of 60-70 %, If 80 % efficiency is achieved in conventional air coolers, then cost is increased due to the use of better quality cooling pads such as cellulose pads.

The product reduces the formation of aerosols as well.

**Over all this product, if developed on large scale can surely create an impact, and can serve as the alternative to existing air coolers at low cost and easy manufacturing.**

Fig 1.2.2 (a) and (b) and (c) shows the complete CAD model of the design. There is a duct placed in the center of the model. The air is sucked from the atmosphere with the help of fan placed on the top of the model. The air is allowed to travel through the duct. Inside the duct there are two evaporative media, which are wetted from water, pumped with the help of water pump and transferred to the pads with the help of pipe. Jointly they form the water distribution system. The air then strikes the water surface of the water kept inside the mud pot. The whole process is explained with the help of a flow chart. ( Fig 1.2.1)

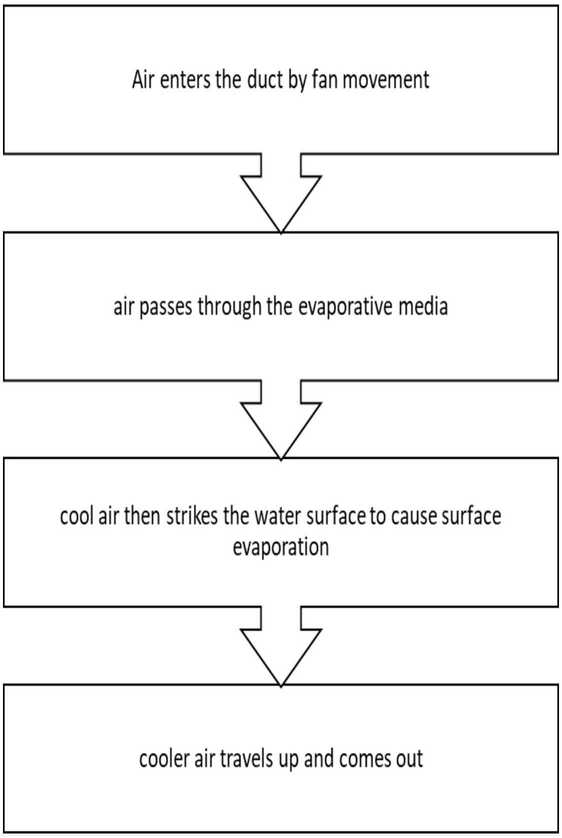


Fig1.2.1 (Flow chart)

Fig 1.2.2 (a)

1.2.2(b)

1.2.2©

Table 1.3 A look in to the historical journey of DEC [21]

| Sr. No. | Author Name | Description |
|---|---|---|
| 1 | Aimiuwu (1992,1993) | found the long term temp of water in a porous ceramic pot below the ambient temp |
| 2 | Taha et al (1994) | observed a temp depression in a box shaped evaporatively cooled chamber |
| 3 | Anyanwu (2004) | measured the transient response of an ECC to changes in ambient RH and temp during dry and wet seasons |
| 4 | Dash, Chandra (2001) | studied on the influence of structural and operational parameter on the interior environment of an ECC |
| 5 | Upchurch, Mahan (1998) | found the characteristic leaf temperature of well watered cotton plant |
| 6 | Prange (1996) | found insects uses evaporative cooling as a thermoregulatory mechanism |
| 7 | Fu et al (1990) | concluded that thermal radiative heat flux decreased due to the presence of an evaporative water filnm |
| 8 | Kassem (1994) | studied theoretically and experimentally on the increasing the water evaporation efficiency of the pad |
| 9 | Giabaklou, Ballinger (1996,2003) | proposed a system that used the evaporative cooling effect of water |
| 10 | Ibrahim et al (2003) | measured dry bulb temp drops of 6-8C with a 30% increase in the RH of the inlet air |
| 11 | Dai , Sumathy (2002) | uses the honeycomb paper is used as the packing material through which the air stream is cooled |
| 12 | Tang, Etzion, Cheikh, Bouchair (2004) | They developed model for predicting the thermal performance for cooling building in hot and cold climate |
| 13 | Zalewski, Gryglaszewski (1997) | They developed heat and mass transfer model for evaporative fluid cooler |
| 14 | Armbruster, Mitrovic (1998) | developed correlations for the Nusselt number |
| 15 | Song et al (2003) | concluded that evaporation would significantly increase the cooling effect |
| 16 | Qureshi, Zubair (2005) | studied the impact of fouling on the performance of evaporative coolers and condensers |
| 17 | Dagtekin (2009) | studied the performance of pad evaporative cooling system in boiler |
| 18 | Workneh (2009) | work on forced ventilation evaporative cooling during storage and found the effectiveness of system |
| 19 | Tilahun (2010) | find the feasibility and economic evaluation of low cost evaporation cooling system |
| 20 | Khandelwal (2010) | uses a regenerative evaporative cooling for energy saving opportunity in buildings |
| 21 | El Awad (2010) | studied the solar powered winter air conditioning system using evaporative cooler |
| 22 | Maheshwari (2001) | studied potential of indirect evaporative cooling |
| 23 | Chaktranouda, Doungsong | evaluate energy saving opportunity in split air conditioning by using indirect |
| 24 | Qiang et al | established a neutral network model to predict the air handling performance of DEC under various working condition |
| 25 | Du et al | obtain the cooling efficiency formula of DEC as a function of the pad thickness, heat transfer coefficient, face velocity and specific pad surface |
| 26 | He et al | studied film media used for evaporative pre-cooling of air to improve the cooling performance |
| 27 | Xuan et al | introduced the working principles and thermodynamic characteristics of different types of evaporative cooling |
| 28 | Heidarinejad et al | discuss the result of performance analysis of a ground-assisted hybrid evaporative cooing system in Tehran |
| 29 | Kachhwaha, Prabhakar | present efficient methodology to design a house hold desert cooler, predict the performance of evaporative medium and determine pad thickness |
| 30 | Basediya et al | reported basic concept and principle, methods of evaporative cooling and their application for the preservation of fruit and vegetables and economy also |
| 31 | Chen et al | Presented a case study of a two stage DEC air condition application. The result showed that the indoor temperature and humidity level can be maintain |
| 32 | M. Jradi | presented Experimental and numerical investigation of a dew-point cooling system for thermal comfort in building |
| 33 | Joohyun Lee | presented experimental study of a counter flow regenerative evaporative cooler with finned channels |
| 34 | Aftab Ahmad | presented performance evaluation of an indirect evaporative cooler under controlled environmental conditioned |
| 35 | Frank Bruno | presented On-site experimental testing of a novel dew point evaporative cooler installed in both commercial and residential application |

## 2. Simulation

The simulation of the design was done with the help of python programming language. A simulation model was created using various mathematical equations combined together to calculate various parameters such as leaving temperature of air, saturation effectiveness, rate of evaporation, cooling capacity etc. The list of various parameters is explained below.

### 2.1 Saturation effectiveness

The various parameters such as volume of air leaving the cooler, dry bulb temperature of the cool air, wet bulb temperature, humidity were observed to check the efficiency of the new model. The saturation effectiveness is calculated for the prototype, the cooling capacity and the theoretical volume that the prototype can cool were calculated.

The main parameter considered when evaluating the performance of direct evaporative coolers is the Saturation Effectiveness (η), which can be defined as:

$$\eta = \frac{DBT1 - DBT2}{DBT1 - WBT1}$$

Where η is the saturation effectiveness, DBT1is the outdoor air Temperature, DBT2 is the supply air temperature and WBT2 is the outdoor air wet bulb temperature. The value of the Saturation Effectiveness depends on the following factors:

- Air velocity through the cooler: For a specific cooler, with a particular, and thickness of evaporative media and water flow, the saturation efficiency may decrease or increase depends on the material, in our model for coconut fibre the effectiveness decreases when velocity is increased too much. And effectiveness of surface evaporation increases with increase in velocity.
- Dry Bulb temperature of entering air
- Specific humidity of entering air
- Temperature of the water inside the container
- Wetness of pads

The cooling capacity of the cooler can be calculated by using the given equation:

Q= Ma x Cp x (DBT1-DBT2) x 3600 (kJ/h)
Ma=ρ x $V_a$ x H x W (kg/sec)

Where, Q is the sensible heat/cooling capacity (W), Ma is mass of air flow, $V_a$ is the air velocity (m/s), H x W is the area section ($m^2$) and ρ is the density (kg/m3). In the majority of the direct evaporative coolers, velocity must not exceed 3m/s to prevent generation aerosols.

### 2.2 Rate of Evaporation:

Rate of evaporation is very crucial in finding out the temperature of the cool air leaving the air cooler. In conventional air cooler the evaporation rate is the amount of water that is added to the airflow as a result of the energy transfer between airflow and water, and the subsequent evaporation of water into the air. The amount of water evaporated into the air or evaporation rate will depend on the entering ambient air conditions. Factors such as dry bulb temperature, relative humidity, and air ambient pressure determine the maximum amount of water that may be evaporated before air becomes "saturated" with water. Here, $m_{air}$ = Mass airflow rate (lb. dry air/min) at entering conditions $V_{air}$ = Specific volume of air ($m^3$/kg. dry air) at entering conditions Similarly, since the evaporation rate is a function of the temperature of the ambient air and airflow, the amount of water evaporated may be obtained from the energy balance equation between air entering and leaving the evaporative cooler media:

$$\text{Evaporation} = \frac{m_{\text{air}} C_{p_{\text{air}}} \left(T_{DBE} - T_{DBL}\right)}{\rho_{\text{water}} h_{fg\,\text{water}}}$$
$$= \frac{\rho_{\text{air}} V_{\text{air}} C_{p_{\text{air}}} \eta \left(T_{DBE} - T_{WBE}\right)}{\rho_{\text{water}} h_{fg\,\text{water}}}$$

Where:
$T_{DBL}$ = Dry bulb temperature at leaving from evaporative cooler.
$T_{DBE}$ = Dry bulb temperature at entrance to evaporative cooler.
$T_{WBE}$ = Wet bulb temperature at entrance to evaporative cooler.
$C_{Pair}$ = Specific heat of air at $T_{DBE}$ (Btu/lb. °F)
$H_{fgwater}$ = Heat of evaporation of water (Btu/lb water) at $T_{WBE}$

For practical purposes, the following version of the energy balance equation is used:

$$\text{Evaporation} = \frac{V_{\text{air}} \left(T_{DBL} - T_{DBE}\right)}{500000} = \frac{V_{\text{air}} \eta \left(T_{DBE} - T_{WBE}\right)}{500000}$$

In conventional air coolers as the air passes through the evaporative media, the water evaporates and cools the air temperature as shown in the fig 2.1

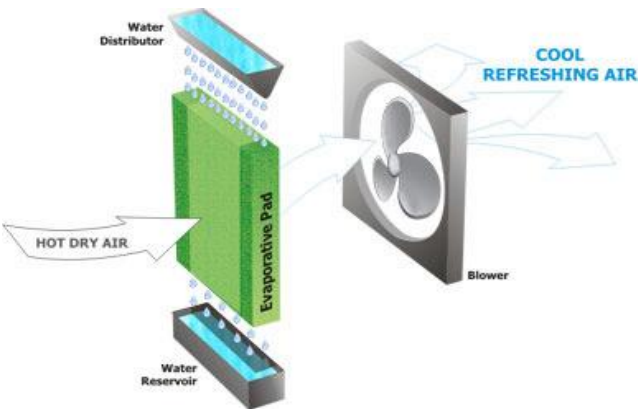


Fig2.1 Evaporation in conventional air coolers with pads

The evaporation rate in the new mud pot cooler is the surface evaporation as in the swimming pools and water bodies. The evaporation is much dependent on the velocity of air striking and the specific humidity of air. The fig 2.2 shows the fundamentals of surface evaporation. The rate of evaporation due to the velocity of air above the water surface is given by the following formula:

- $G_s = \Theta A (x_s - x) / 3600$ (Kg/sec)
- $G_h = \Theta A (x_s - x)$ (Kg/hour)

The above stated empirical formula is only valid when the air velocity above the water surface is equal to the water surface temperature i.e. the water surface temperature is equal to the temperature of air above it. It is explained in *Dimensionless evaporation rate from free water surface at tubular artificial flow in Sustainable Solutions for Energy and Environment, EENVIRO 2016, 26-28 October 2016, Bucharest, Romania by Tibor Poósa, Evelin Varjua.* And the online website *Engineeringtoolbox.*

Where,

- *gs* = amount of evaporated water per second (kg/s)
- *gh* = amount of evaporated water per hour (kg/h)
- $\Theta$ = *(25 + 19 v)* = evaporation coefficient (kg/m2h)( for a general pool)
- *v* = velocity of air above the water surface (m/s)
- *A* = water surface area (m2)
- *xs* = maximum humidity ratio of saturated air at the same temperature as the water surface or air above water surface (kg/kg) (kg H2O in kg Dry Air)
- *x* = humidity ratio air (kg/kg) (kg H2O in kg Dry Air)

The above stated evaporation rate is because of the air velocity and the difference between the humidity ratio of air and maximum humidity ratio of saturated air at the temperature of water surface. Here the water surface temperature is more than the temperature of water inside the container and less than the temperature of ambient air. The evaporation rate of water is maximum when the surface water temperature is equal to the temperature of ambient air.

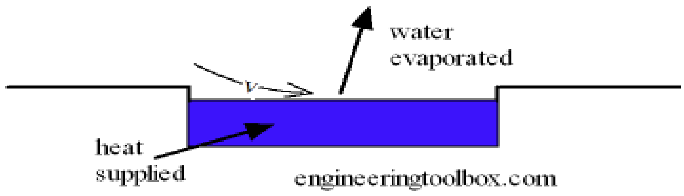


Fig.2.2 Surface evaporation

The evaporation through cooling pads is quite difficult to estimate, hence the adiabatic process parameters are determined by using psychrometric charts. Various research papers were studied to check the saturation efficiency of evaporative media under various air flow velocities and thickness.

By referring "An *Experimental Analysis of Direct Evaporative Cooler by Changing its Cooling Pads, International Research Journal of Engineering and Technology (IRJET), by Kapish T. Dhakulkar1, Mr. Vaibhav Hinge2, Mr. Shivam Kolhe3, Mr. Rajeshwar Chaudhari4, and Mr. Shubham Mahalle5*", it was quite clear that thickness of pads plays a crucial role in saturation effectiveness of the media. The experimental data associated with the research paper were used in the product. **It was found out that the combination of wood wool pad (2cm thick) and coconut fibre pad (2 cm thick) when used together** , give **a saturation efficiency of around 64.38 % with a general exhaust fan with air velocity of around 3 m/s**. By referring to the research paper "*Laboratory Performance Of Evaporative Cooler Using Jute Fiber Ropes As Cooling MediaR.K.Kulkarni et al. Int. Journal of Engineering Research and Applications by R.K.Kulkarni, S.P.S. Rajput, S.A.Gutte, D.M.Patil*" It was clear that around **2.4 m/s velocity air is capable of providing 62.1 % efficiency with loosely packed jute fibres as cooling media.**

From the research paper "*Experimental Analysis of Cellulose Cooling Pads Used in Evaporative Coolers by Dipak Ashok Warke1, Samir Jaiwantrao Deshmukh In International Journal of Energy Science and Engineering*" It was clear that the saturation effectiveness is dependent on the combination of pad thickness and air velocity, The graphs plotted in above stated research papers helped to develop the theoretical model to simulate the actual results.

Here the efficiency of combined evaporative media is 64.38% and the same is taken as the average saturation efficiency for air velocity between 2.9 m/s to 3.2 m/s and the further calculation is done to calculate the overall efficiency of the model.

A theoretical model is developed on python program to get an insight of the various outputs with respect to the input of fan cfm, ranging from 50 cfm to 55 cfm, and the graph is plotted for the same. Fig 2.3 shows the python program developed.

sure that we are able to achieve efficiency more than 75% by using the 3 layers of evaporation, which are the evaporation through evaporative media and the surface type evaporation. As the cool air moves up, the heavy drops of water are not carried with air, hence no aerosol is carried with air.

The variation of saturation effectiveness or saturation efficiency is also plotted. It was observed theoretically that the saturation efficiency increases as the speed of the fan increases, or we can say that the increase in CFM of the fan, increases the saturation efficiency. The plotted graph is shown in fig 2.4.

```
def DT(cfm):
        combinedefficiency=0.6438                  ## assuming good wetting of pads
        DBT=33                                      ## inlet temp of ambient air
        WBT1=22.3                                   ## WBT remains same
        DBT1=26                                     ## temp after pads
        X1=0.018258                                  ## specific humidity at 85% RH and 26 degree temp
        Area=3.14*0.25*0.24*0.24                   ## Area in (m2) of mudpot ## friction losses are zero
        v=cfm*0.02831*0.01667/(3.14*0.25*0.1016*0.1016)
        k=(25+19*v)          ## evaporation coefficient from open surface due to velocity of air(c1+c2*v)
        X=0.0212858                   ## maximum humidity ratio at 26 degrees
        evaporation=(k*Area*(X-X1)/(3600))         ## evaporation of water in kg/sec from open water surface
        evaporation1=k*Area*(X-X1)
        ma=1.1459*cfm*0.02831*0.01666                ## mass of air in kg/sec
        hfg=2430.3                                      ## hfg in kj/kg at 26.293(WBT1) degree
        cpa=1.0069                                         ## cp of air in kj/kgk
        vol= 0.287*(DBT1+273)/(100)                        ## specific volume of air at inlet
        DT = (500000*evaporation/(vol))
        DBT2=DBT1-DT
        effectiveness_surface= (DBT1-DBT2)/(DBT1-WBT1)
        effectiveness_net=(DBT-DBT2)/(DBT-WBT1)
        BTU=3852.308                                  ## BTU corresponding to 3*3*3 m3 room
        req=DBT2+BTU/(1.08*cfm*1.25)                       ## sensible heat removal method
        print ('velocity of sucking air:')
        print (v)
        print ('mass of air :')
        print (ma)
        print ('leaving air DBT :')
        print (DBT2)
        print ('temperature difference is due to surface evaporation:')
        print (DT)
        print ('effectiveness with only pads')
        print (0.6438)
        print ('effectiveness of surface evaporation is:')
        print (effectiveness_surface)
        print ('effectiveness_net is:')
        print (effectiveness_net)
```

Fig2.3 Theoretical model to calculate saturation efficiency

Theoretically the saturation efficiency of the system is nearly 82% at 50 cfm (2.9 m/s) fan and is nearly 83.2% for 55 cfm (3.2m/s) fan. The fig 3.6 shows the theoretical calculation of the model, the real experimental data may vary, but it is for

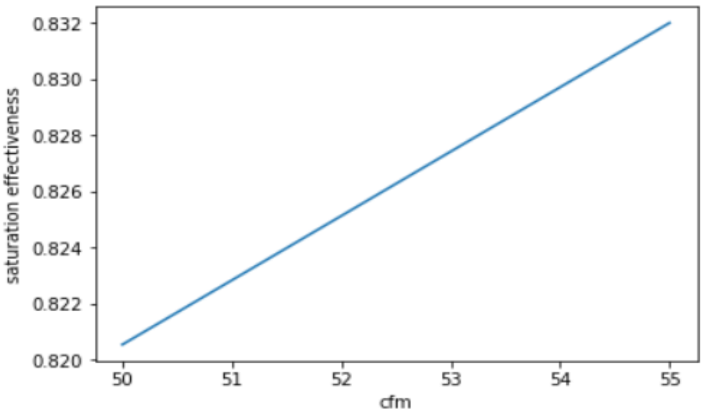


Fig 2.4 Variation of saturation effectiveness with cfm of fan

## 3. CONCLUSIONS

The low cost mud pot air coolers works on the principle of direct evaporative cooling. Where the air comes in direct contact with water surface or wet evaporative media. The model developed is a highly efficient , theoretically. The design of the product is unique and the cost of manufacturing of the product is also very less because of the use of mud pots. The efficiency achieved with the use of two evaporative media pads and the surface evaporation phenomenon is more than 80% when 50 cfm, 4 inch fan is used and the efficiency keeps on increasing with increase in the speed of the air striking the pads and water surface. The product if developed on a large scale can create job opportunities for rural regions where mud pot craft is highly practiced. The major benefit of such a design is that the aerosol formation is eliminated which is very much observed in common desert coolers. The product find its vast use for cooling areas in commercial complexes, houses, offices and even IT centers.

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