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Research and Study of an Evaporative, Desiccant Based Cooling System

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ABSTRACT

The significant shift in climatic conditions in recent years, the demand of air conditioning is growing entire the world. This results in a large amount of primary energy usage. To offer the highest indoor air quality and thermal comfort while spending the least amount of money, usage of energy, in our daily lives, we have the choice of using a desiccant cooling system. A theoretical performance analysis of the desiccant cooling system was conducted in this paper. The impacts of various factors on system performance have also been studied. It is correct. It was discovered that the effect of the examined factors lowered the dehumidification rate.

I. INTRODUCTION

Desiccant cooling systems are low-energy and ecological friendly. Desiccant dehumidification, according to one estimate, may reduce overall residential energy demand by 25 percent in humid areas, resulting in a drier, a more sanitary and pleasant indoor environment with a reduced utility bill desiccant systems bring more fresh air into buildings, therefore improving indoor air quality without the use of chemicals more vigour. Desiccant systems also eliminate the need for chlorofluorocarbon-based cooling equipment, the emissions from which contribute to global warming. The ozone layer on Earth is being depleted. When fresh outside air is introduced inside a structure, it bears a high humidity burden in comparison to the internal latent load of the structure Traditional vapor-compression cooling methods are unsuitable for efficiently treating high humidity loads. To ensure that the air within is suitably dry Vapor-compression has a wide range of uses. Low-temperature systems must be used as a result of which their efficiency is reduced and ineffective warming of dry, cold air reach a certain level of comfort Furthermore, the wide spread usage of large compressors controlled by dry-bulb valves exacerbates the situation of fix points This results in short-cycling can reintroduce moist cooling condensate The coil is then reintroduced into the supply air. Desiccant cooling systems are used to improve the interior air quality of all types of buildings by effectively managing significant amounts of moisture, fresh aerating air in these systems, is a desiccant of substance that absorbs moisture from the air heat and it is released as a result of a process known as absorption and raises the temperature of the air.

Many of academics have examined an extensive research on cooling system of desiccant solid and their various features. The works mentioned are as follows:

Performance in relation to feasible studies technology, forecasts ,assessments ,enhancements, optimization, and the creation of novel materials & the investigation of its impact on desiccant of cooling system as they age improvement of the system unit, etc. Jain and others [1] suggested four of the cycles (the recirculation cycle, the ventilation cycle, the dunkle cycle, and the recirculation cycle). Cycle of wet surface heat exchangers) for different of outside conditions (Dry-bulb temperature) , (as well as wet-bulb temperature) of a number of Indian cities. The study's goal was to assess the impact of heat exchanger and evaporative cooler performance on the cooling coefficient of performance (COP) is defined as well as the rate of air volumetric circulation in various environmental conditions. Mavroudaki et al. [2] and Daou et al. [3] investigated the possibility of solar-powered desiccant. The cooling rate in the European town to illustrate the continent of climate zones.

The authors' findings indicated that main energy reductions were realised of all weather situations a drop in Savings of energy were seen in much humid areas. The high cost of living was cited as the cause of this drop necessary temperature to renew the high humidity conditions necessitate the use of a desiccant. Jain and Dhar [4] investigated the seasonal improvement of two desiccant cycles of cooling in conjunction with dehumidifier of a silica gel: Pennington term (ventilation period) (it is the most commonly utilized) as well as the recirculation cycle.

Meckler [5] has highlighted the numerous advantages of desiccant technology, its prospective uses, and the reasons that drive its development. Future development several silica gel-based there have been advancements in the development of composite desiccants jia et al. [6] investigated this.

SYSTEM CONFIGURATION AND WORKING PRINCIPLE

Desiccant cooling entails the dehumidification of incoming air flow from pushing it by a desiccant substance and after drying the air for removal of moisture the ideal interior temperature for accomplishing this, water vapour circulates throughout the system at all times absorbed must be expelled from the desiccant substance (resurgence) in order for it to be sufficiently dry to absorb the water vapour in the upcoming cycle, which is accomplished through heating the material of desiccant to its resurgence temperature, which is evaluated by the type of used desiccant material. A desiccant is anything that absorbs moisture. As a result, the cooling system consists of primarily three elements, namely the heat source for resurgence, as well as the dehumidifier (of desiccant substance), and cooling system. The effectiveness of a desiccant unit is heavily dependent on Sensible Heat Ratio (SHR).
The “SHR” is given as the ratio of sensible heat gain to the total heat gain of the space to be conditioned. A small value of its figure represents entire cooling capacity is mostly the latent load, at which the desiccant cooling has been shown to be essential in a variety of situations to be efficient and cost-effective.

COMPONENTS

Evaporative Cooler

Evaporative cooling occurs naturally. It's similar to how when the wind blows off the sea, it causes water to evaporate, and thus the temperature will drop. Common needs include a surface that allows for water evaporation and a water supply system that may moisten the surface, as well as control methods that enable air to travel through the surface in order to create an effective the overall operation of the system.

An evaporative cooling system uses induced heat and mass transfer processes with water and air as working fluids. It consists, particularly, of water evaporation caused by the passage of an air flow, which lowers the temperature of the air. When water evaporates into the air to be cooled while also humidifying it, this is referred to as direct evaporative cooling (DEC), the heating process corresponding to as the adiabatic state of saturation. Indirect evaporative of cooling occurs when the air is going to be cooled is placed apart from the process of evaporation and so is dehumidified while being of cooled (Figure 1).

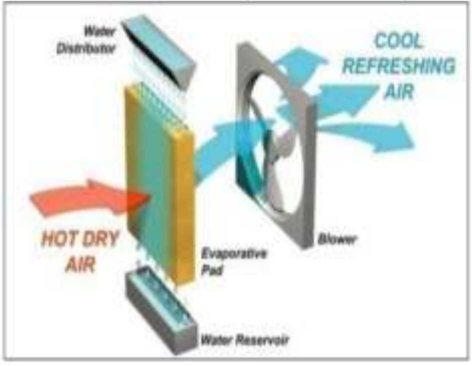


Fig. 1: Evaporative Cooler.

Desiccant Wheel

A desiccant wheel is a circular honeycomb matrix of moisture-absorbing material that is gently spun within an air handling system's supply and exhaust air streams. A coating is applied to the air stream only for the purpose of dehumidifying or "drying" it. Typically, silica gel is used as a desiccant. As the wheel spins, the desiccant alternatively passes through the entering air, where moisture is absorbed, and through a "regenerating" zone, where the desiccant is dried and moisture is ejected. The absorbent process is repeated while the wheel continues to revolve. Resurgence is often accomplished through the use of a heated coil. Desiccants are chemicals that have the capacity to absorb water vapour. As a result, they may be utilized not only to overcome the latent cooling load of air conditioning systems and enhance indoor air quality, but also to dehumidify air for any industrial application.

A variety of hybrid air conditioning systems have recently been proposed as alternatives to standard vapour compression cooling systems, in which desiccants (solid and liquid) were employed to reduce latent cooling load and regular air conditioners were utilized to provide sensible cooling. These systems were designed to save energy. These systems were built differently and used different techniques of desiccant resurgence. The heat required to raise the temperature is equivalent to resurgence energy. Surface vapour pressure greater than that of the surrounding air, plus the heat required evaporating the moisture it contains It has a high water affinity and may absorb air moisture (Figure 2).

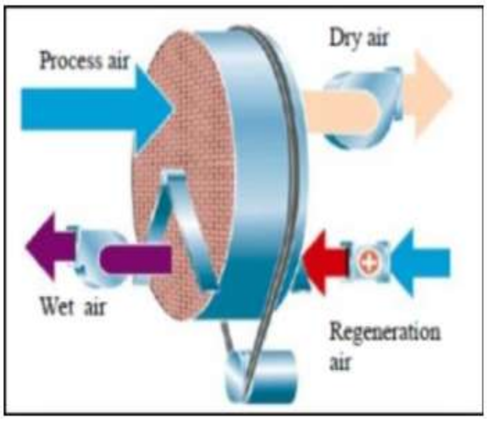


Fig. 2: Desiccant Wheel.

Thermal Wheel

A thermal wheel is a rotating element made by rolling up the sheets of a metallic material (like aluminum) to create a more number of the parallel channels by characteristic sinusoidal of cross sectional in shape. The supply air flow, which is the fresh air flow, and the exhaust air flow, which is the return air flow from room, both travel through the device's cross sectional area. To prevent sludge of the fresh air charge, a purge sector is frequently utilized between the exhaust and supply air streams. Heat is transmitted from one flow of air to matrix of wheel, and subsequently from the matrix to another flow.

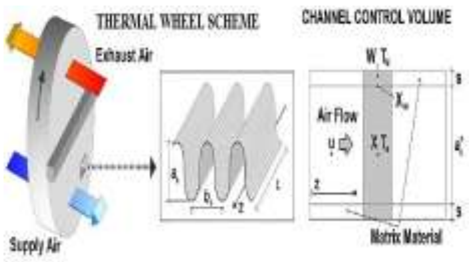


Fig. 3: Scheme of Heat Wheel and Channel Control Volume.

WORKING PRINCIPLE

The desiccant cooling air handling unit is depicted in Figure 3. It is made composed of a desiccant wheel and the thermal (heat) wheel, having coolers of evaporative in both the supply and return air flow before of thermal wheel. The unit is capable of chilling and dehumidifying air without the use of traditional refrigerants.

A desiccant substance (silica gel) is contained within the desiccant wheel and must be renewed using an external heat source.

Temperatures necessary for resurgence are modest (40–70 °C). Based on outside of air state and of building loads, air installation having 5 operating modes:

1. Ventilation mode for the supply of fan (D-E) runs.
2. Humidification mode of direct supply of air is humidified (C-D).
3. Humidification mode of Indirect where the supply of air is sensibly cooled by a revolving heat exchanger (B-C). On another side of heat exchanger, back air is cooled by the humidification (G-H).
4. Combination of direct and indirect humidification mode in which both humidifiers and revolving heat exchanger are running on.
5. Desiccant mode of outdoor air is dehumidified by help of the desiccant wheel.

Almost adiabatically, the air has dehumidified throughout vapour absorption of wheel (A-B).

Its temperature rises as its humidity ratio falls. The temperature is then reduced in the revolving heat exchanger from (B-C) and of direct humidifier (C-D).

Back air is cooled by an evaporative cooler from (F-G) before being utilized to cool the process of air in the heat exchanger (GH).

The desiccant wheel is then heated to renew it (J-I).

Figure 4 is a psychometric chart that depicts the process and exhaust air conditions.

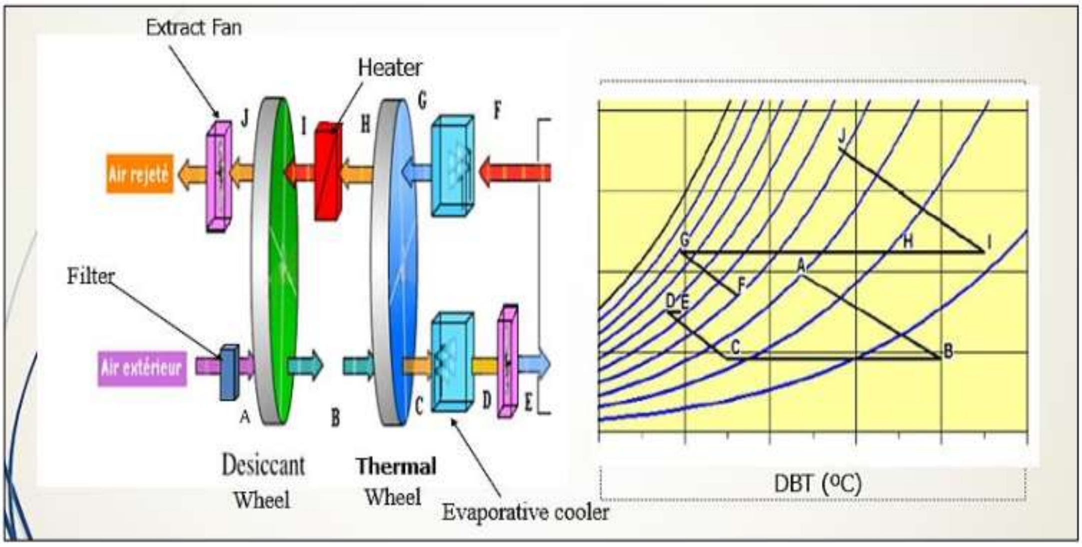


Fig. 4: Schematic Representation of the Desiccant Cooling System and Process in Psychrometric Chart.

Table 1: Inlet Condition of Moist Air at Desiccant Wheel.

S. No.	Wet bulb temp. (°C)	Dry bulb temp. (°C)	Sp. Humidity (ω) (Kg/Kg of dry air)	Relative humidity (ϕ) (in %)	Enthalpy (h) (KJ/Kg)
1	18	33	0.00756	64.198	52.5372
2	20	35	0.00891	65.544	58.1176
3	22	37	0.01064	67.163	64.5362
4	26	41	0.01501	70.692	79.8845
5	28	43	0.01768	80.413	88.8522
6	30	45	0.02074	81.041	98.7367
7	28	40	0.01895	73.631	89.0255
8	30	42	0.02199	77.192	98.9192
9	25	35	0.01591	72.946	75.9921
10	30	38	0.02372	77.162	99.1624
11	28	34	0.02152	71.732	89.3683

During the height of summer, an evaporative desiccant cooler was studied. Outside air enters the evaporative desiccant cooler under the following conditions: The dry bulb temperature of outdoor moist air ranged from 33 to 45 degrees Celsius, while the wet bulb temperature ranged from 18 to 30 degrees Celsius. As a result, the equivalent relative humidity ranged from 64% to 81%. Table 1 depicts the fluctuation of moist air inflow condition.

Volume of air in room = Volume of room

=3.048×3.048×3.048m3
=28.31m3
Moisture removal capacity = 0.0008736Kg/min

Amount of water added after evaporative cooler

=0.89578 m3/Kg of dry air.
For desiccant wheel following specification has utilized:

Desiccant Wheel Specification
Thickness of desiccant wheel = 10 mm
Diameter of desiccant wheel = 900 mm
Considering the desiccant wheel as the shape of cylinder
Total amount of silica gel in desiccant wheel=23Kg
Density of silica gel (ρ) = 730Kg/m3.
Mesh size of silica gel grade A = 10–40.

Formulae that were used for analysis of air in desiccant wheel:
Volume (V) of desiccant wheel = πr2h (1)
Where, r is radius & h is the thickness of desiccant wheel.
Mass of the silica gel = ρ×V
(2)
Where, ρ is density of silica gel.

Mesh size of silica gel = 10–40
Mesh is a technique for determining the particle-size distribution of granular materials.
Size of 1 mesh = 2243 × 10-6 m
= 2.243 × 10-3m
Size of 40 mesh = 0.0897 m

Volume of one grain of silica gel =4/3 π r3
(3)
Moisture removal capacity (MRC) is the ability of a desiccant to extract water vapour from wet air. It is measured in kilogram per hour. It may be calculated using the following equation:
MRC = 0.0006429 × Q × No. of grain
(4)
Where, Q is the total value of air at inlet of desiccant wheel.
Specific humidity at outlet (ωo) of desiccant wheel is calculated by following formula:
ωo = ωi – MRC
(5)
Since,
twb= wet bulb temperature of moist air.
hi = ho = inlet and outlet enthalpy of moist air.
h = (1.005×tdb) + [ωo× {2500+ (1.88×tdb)}]

where, tdb = dry bulb temperature of moist air.

Table 2 and Figure 5 show how the state of wet air changes after passing through the desiccant wheel.

The temperature of the desiccant rose as a result of its absorption of water vapour. As a result, the temperature of the air that went through the desiccant dry bulb was raised. The wet bulb temperature of moist air ranged from 18 to 30 degrees Celsius, while the specific humidity ranged from 0.006680 to 0.022846 Kg/Kg of dry air.

The temperature of moist air exiting the desiccant dry bulb ranged from 35°C to 48°C, and relative humidity ranged from 19% to 54% at the departure point of the desiccant wheel and the entry point of the thermal wheel. As a result, of relative humidity of wet air was lowered and the dry bulb of temperature was increased at the desiccant wheel's exit. Desiccant molecules had porous spaces between them, the vapour pressure of desiccant was low, and the partial pressure of the water in an air was high, therefore water was absorbed by desiccant. The air that exits the desiccant wheel travels through the thermal wheel.
The following equations are used to calculate moist air at the thermal wheel:

$$H_t = H_{dry\ air} + H_{water\ vapour} \quad (6)$$

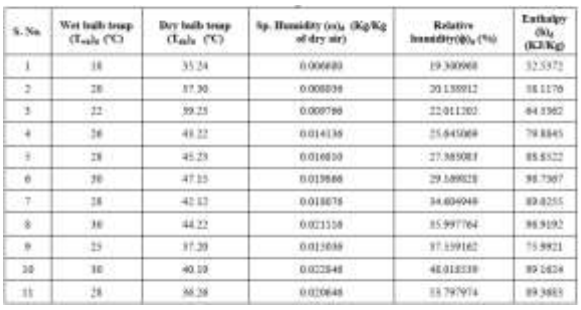
$$H_{dry\ air} = t_{db} \times C_{pa} \times m_{dry\ air} \quad (7)$$

$$H_{water\ vapour} = m_{water\ vapour}[(C_{pw} \times t_{dp}) + \omega(h_{fg})_{dp} + C_{pv}(t_{db} - t_{dp})] \quad (8)$$

$$H_t = UA\{(t_{db})_i - (t_{db})_o\} \quad (9)$$

We get $(tdb)_o$ by solving equation (1) and (2). Because is constant, twb is computed using a psychrometric chart. Table 3 and Figure 6 show the outlet state of wet air that has passed through the thermal wheel.

Table 2: Outlet Condition of Air at Desiccant Wheel.



S. No.	Wet bulb temp $(T_{wb})_o$ (°C)	Dry bulb temp $(T_{db})_o$ (°C)	Sp. Humidity $(\omega)_o$ (Kg/Kg of dry air)	Relative humidity$(\phi)_o$ (%)	Enthalpy $(h)_o$ (KJ/Kg)
1	18	35.24	0.006680	19.300968	52.5372
2	20	37.30	0.008036	20.135912	58.1176
3	22	39.25	0.009798	22.011202	64.3362
4	26	41.22	0.014136	25.645069	78.8845
5	28	45.23	0.016010	27.385083	85.5522
6	30	47.15	0.019866	29.169028	98.7367
7	28	42.12	0.018078	34.604948	89.0255
8	30	44.22	0.021158	35.997764	98.9192
9	25	37.20	0.015036	37.159162	75.9921
10	30	40.10	0.022846	48.018338	99.1624
11	28	36.28	0.020646	53.797974	89.3883

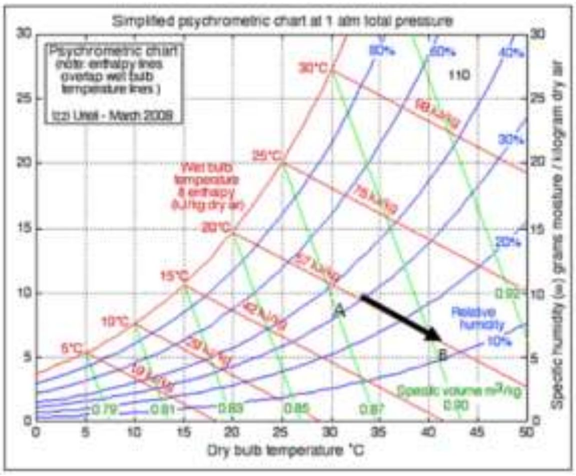


Fig. 5: Condition of Air after Passing through the Desiccant Wheel.

Table 3: Condition of Moist Air After Coming Out from Thermal Wheel.

S. No.	Wet bulb temp. $(T_{wb})_o$ (°C)	Dry bulb temp. $(T_{db})_o$ (°C)	Sp. Humidity $(\omega)_o$ (Kg/Kg of dry air)	Relative humidity $(\phi)_o$ (%)	Enthalpy $(h)_o$ (KJ/Kg)
1	14.24	32.24	0.004646	24.575152	44.285961
2	16.13	34.58	0.005231	25.555486	47.865324
3	18.21	36.43	0.006318	27.857457	52.844118
4	22.19	40.23	0.009562	29.568171	61.839925
5	24.08	42.23	0.011357	31.685085	71.821173
6	26.09	43.15	0.014253	34.061383	80.154880
7	24.12	38.83	0.012911	38.707977	72.269618
8	26.02	40.92	0.015076	38.937613	78.874346
9	26.11	37.18	0.016846	41.548976	80.574196
10	21.18	34.28	0.010701	32.723923	61.893383
11	24.13	33.24	0.015292	57.699692	72.592545

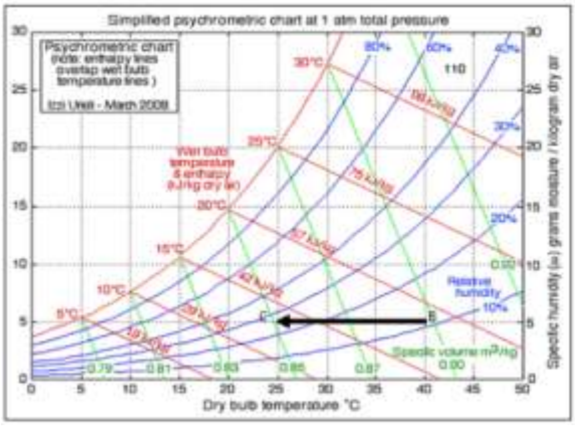
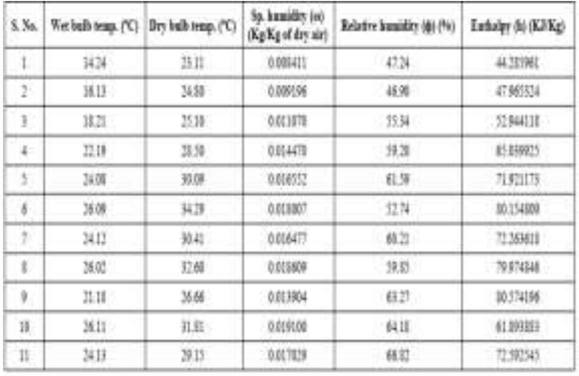


Fig. 6: Condition of Moist Air After Coming Out.

When air was passed through the thermal wheel, the specific humidity remained constant. As a result, the temperature of the air that went through the thermal wheel dry bulb was reduced. Here, the wet bulb temperature of moist air ranged from 14 to 27 degrees Celsius, and the output of thermal dry bulb temperature of moist air ranged from 32 to 44 degrees Celsius.

Relative humidity ranged from 24 to 58 percent at the exit point of the thermal wheel and the entry point of the evaporative cooler. As a result, at the thermal wheel's output, relative humidity of the moist air increased while temperature of the dry bulb decreased. After passing through the thermal wheel, the air is routed to the evaporative cooler. Table 4 and Figure 7 depict the state of wet air.

Table 4: Condition of Moist Air Coming Out from Evaporative Cooler.



S. No.	Wet bulb temp. (°C)	Dry bulb temp. (°C)	Sp. humidity (ω) (Kg/Kg of dry air)	Relative humidity (ϕ) (%)	Enthalpy (h) (KJ/Kg)
1	14.24	23.11	0.008411	47.24	44.281981
2	18.13	24.80	0.009196	46.90	47.965524
3	18.21	25.10	0.011078	55.34	52.944118
4	22.18	28.50	0.014478	59.28	65.039925
5	24.08	30.08	0.016552	61.58	71.921175
6	26.08	34.28	0.018007	52.74	80.154809
7	24.12	30.41	0.016477	60.21	72.363618
8	26.02	32.60	0.018809	59.83	79.974848
9	21.18	36.66	0.013904	63.27	80.574196
10	26.11	31.81	0.019100	64.18	61.093883
11	24.13	29.15	0.017829	68.82	72.592545

An evaporative cooler is a device that uses spray water to cool the air by decreasing the temperature. In general, adding water vapour to the air decreases the temperature.

When air passes through an evaporative cooler, the sensible heat of the air converts the water droplet of the cooler pad into water vapour, which gets latent heat due to phase transformation of water, and the wet bulb temperature of moist air varies from 14°C to 27°C due to latent heat of water vapour and the dry bulb temperature of wet air ranged from 23°C to 35°C, while relative humidity varied from 46 percent to 67 percent at the evaporative coolers departure point.

As a result, at the evaporative coolers outlet, the relative humidity of the moist air increased while the dry bulb temperature decreased.

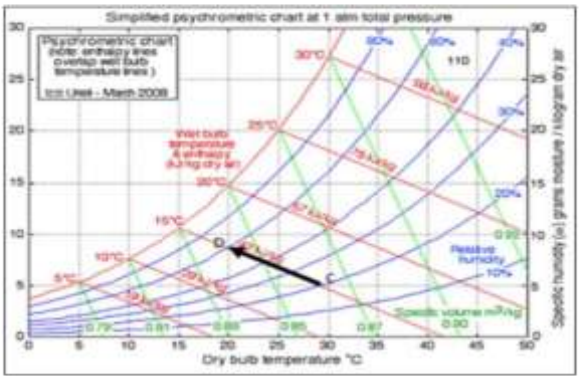


Fig. 7: Condition of Moist Air Coming Out From Evaporative Cooler.

II. CONCLUSION

Desiccant evaporative coolers are a viable approach for reducing humidity in desert coolers and running them during the wet season. A model of a desiccant wheel was examined in this paper. According to the results, this technique produces relative humidity in the human comfort zone. The moist air's dry bulb and wet bulb temperatures were decreased. The performance of an evaporative desiccant cooler is superior to that of an evaporative cooler, and it is more environmental friendly.

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