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Energy Performance Evaluation of Desiccant Based Air Conditioning Test Rig

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ABSTRACT: A desiccant is a solid or liquid which dries air by attracting water molecules onto the desiccant surface. The dry air is then cooled by direct or indirect evaporation and sent to the air conditioned space. After the desiccant becomes saturated, it is heated to release the moisture it attracted from the air. This is called "reactivating" the desiccant. In traditional A/C system which is based on Vapour Compression Refrigeration (VCRs), the air is cooled up to its Dew Point Temperature (DPT), for dehumidifying it and it is heated up to required temperature. But in Desiccant based hybrid A/C system, the air is passed through desiccant material where it dehumidifies the air by absorbing moisture from air and then air is cooled up to required temperature. By incorporating desiccant dehumidification with traditional VCR system, it reduces the energy cost which is required in traditional VCR system to cool the air up to its Dew Point Temperature (DPT), for dehumidifying it. The latent load can be reduced by desiccant material. This study aims to evaluate energy performance for the given test rig.

KEYWORDS: desiccant, silica, humidity, temperature, air conditioning

I. INTRODUCTION

The heating, ventilation, and air conditioning (HVAC) industry is facing several challenges in the 1990s, including a decrease of energy resources, an increase in energy demand due to population growth, and new regulatory policies. To respond to these challenges, more energy-efficient heating, cooling, ventilation, and dehumidification technologies are needed. However, there are a number of constraints for deployment of energy-efficient HVAC technologies; among them are the imminent phase-out of chlorofluorocarbons (CFCs), eventual phase-out of hydro chlorofluorocarbons (HCFCs), and the increase in ventilation rates for buildings because of concerns regarding indoor air quality and occupant health. The higher ventilation rates translate into greater cooling loads-in particular, greater latent loads during cooling seasons when the relative humidity within a building must be kept sufficiently low to inhibit the growth of micro-organisms that cause health problems and also may damage building materials. As a result, air dehumidification has become a very important part of the HVAC function.

Desiccant dehumidification technology has a successful track record over more than 60 years for industrial applications such as product drying and corrosion prevention. It has also been used for many years in clean rooms, hospitals, museums, and other special cases requiring highly controlled humidity levels. Desiccant materials attract moisture based on differences in vapor pressure. Due to their enormous affinity to absorb water and considerable ability to hold water, desiccants have been widely applied to marine cargo, pharmaceutical, electronics, plastics, food, storage, etc. Recently, the rapid development of desiccant air conditioning technology, which can handle sensible and latent heat loads independently without using CFCs and consuming a large amount of electric power, and thus meet the current demands of occupant comfort, energy saving and environmental protection, has expanded desiccant industry to a broader niche applications, such as hospitals, supermarkets, restaurants, theatres, schools and office buildings. The basic idea of desiccant air conditioning is to integrate the technologies of desiccant dehumidification and evaporative cooling together. While the former adopts water as refrigerant and can be driven by low grade thermal energy as solar energy, district heating, waste heat and bio energy, the later is near-zero cost technology. These indicate that desiccant air conditioning would be not only energy efficient and environment-friendly but also cost-competitive, especially for hot dry and hot humid areas. Besides, since desiccants remove moisture in the vapor phase without liquid condensate, desiccant dehumidification can continue even when the dew point of the air is blew freezing; in contrast, cooling-based dehumidification is limited by freezing phenomenon occurring at 0.8C. As a result, desiccant air conditioning is

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capable of handling the dew point of the air to40c, whereas the counterpart of traditional vapor compression air conditioning As desiccants can be either solid or liquid, desiccant air conditioning systems can be classified into two categories, namely, solid desiccant air conditioning systems, which consist of fixed bed type and rotary wheel type, and liquid desiccant air conditioning systems. Due to being advantageous in handling latent heat load, all these technologies have been used widely. Especially, rotary desiccant air conditioning systems, which are compact and less subject to corrosion and can work continuously, attract more attention. To date, extensive studies on rotary desiccant air conditioning have been carried out on the basis of mathematical simulation, thermodynamic analysis, experimental investigation and practical application. A lot of academic societies, research institutes, universities, companies, etc., have been involved into these works, and significant improvements in system performance, cost and reliability have been achieved.

II. LITERATURE REVIEW

Marco Beccali et al. [1]. the authors have evaluated energy performance of a demo solar desiccant cooling system with heat recovery for regenerating the adsorption material. A Solar DEC Air Handling Unit, airflow 1250 m^3/h, was installed and monitored. Heat rejected by the auxiliary chiller is used for preheating the regeneration airflow. In summer, more than 50% of cooling energy was delivered by the Desiccant evaporative cooling. The Energy savings is about 50% in summer and 27% in winter. S.D. White et al. [1]. the authors have done investigation on Indoor temperature variations resulting from solar desiccant cooling in a building without thermal backup. During study increasing (a) indirect evaporative cooler effectiveness, (b) air flow to the office space, and (c) solar collector area were all shown to reduce the frequency of high temperature events inside the building occupied space. This paper suggests that selected ventilation desiccant cooling cycle is not appropriate for tropical climates. Zahra Hatami et al. [3]. the authors have done investigation on the optimization of a solar collector surface in solar desiccant wheel for cooling process with typical configuration naming desiccant wheel, heat exchanger and water spray evaporative cooler. In this cooling cycle the thermal solar energy has used to heat the regeneration air of desiccant wheel cycle. The results shows that necessary solar collector surface will be decreased by increasing inlet air temperature, inlet air humidity ratio and solar irradiance and will be increased by increasing the regeneration air temperature.

III. OBJECTIVE

- To perform thermal analysis of A.C. system with the help of desiccant.
- To compare desiccant system with the traditional VCRs system.
- Analysis of air conditioning system on ANSYS software and correlate with experimental results.

IV. DESICANT MATERIAL

Practically all materials have some affinity for water vapor. This technically makes them desiccants. However, there are certain properties of commercially viable desiccant materials that separate them from the others. These properties are:

- Chemical and physical stability over many cycles
- Ability to hold large weight fractions of water
- Ability to separate water vapor from other constituents
- Ability to attract water vapor at desired partial pressures.

Many of the materials that are able to attract water vapor do not remain stable during the sorption process. If the structure of the material is altered by the sorption process, chances are that its sorption properties will not remain stable with cycling. Many of the clay materials fall into this category. Viable commercial materials obviously must be able to cycle water in and out of the material many times reversibly.The term "large weight fractions" can be misleading. Lithium chloride, for example, can absorb up to many times its weight in water, while a molecular sieve can absorb only about 25% of its weight. This does not necessarily make lithium chloride a better desiccant material. Other factors come into play when making that judgment. The term "large" is relative to the amount of water common materials will hold. Almost any material will hold what is called a monolayer of water. A monolayer is a surface layer that is one molecule thick. If the amount of surface area per unit of volume for the material is not large, then the amount of water captured will be on the order of 1 to 2%. This water capacity is not considered adequate to make the desiccant a viable material. Many times, the purpose of the desiccant is to separate water vapor from other constituents. In these cases, the

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selectivity of the desiccant will be an important consideration. From our previous example, although lithium chloride will hold much more water per unit mass than molecular sieve, the sieve material will be much more selective in the species that are adsorbed than will the lithium chloride. A great many common materials have the ability to attract and hold large quantities of water vapor. Wool and paper are two materials that possess great affinities for water vapor, but only at vapor pressure close to the air saturation pressure. For many applications, the affinity for water vapor must take place at much lower vapor pressures in order to meet the needs of the application.

V. CLASSES OF DESICCANTS

There are many ways to classify desiccant materials. One obvious way is liquid vs. solid. Another way that is not so obvious is by the sorption mechanism. Absorption refers to the process by which water is bonded within the molecular structure of the material. Adsorption refers to the process by which water is bonded to the surface of the material. Although it is mostly correct to assume that all liquid desiccant reactions are absorption and that all solid desiccant reactions are adsorption, there is one major exception. Hydrates of many metal salts are solid, yet they desiccate by absorption. Another classification used by physical chemists is the concept of physisorption vs. chemisorption. This is an arbitrary designation that reflects the strength of the bond between the adsorbed species (the adsorbate) and the surface of adsorption (the adsorbent). For all practical purposes, the class of adsorption reactions associated with moisture removal from air will always be considered physisorption, and these reactions will have low bond strength. The strength of the bond in moisture absorption must be low in order to make the energy efficiency of a cyclic operation high.

Within the general class of solid desiccants there are several subclasses of materials:

1. Silica.
2. Alumina.
3. Zeolites.
4. Hydra table salts.
5. Mixtures.
6. Liquid Desiccants.

1. Silica

Activated carbons have purposely been left off this list of typical materials. Although activated carbons will adsorb water at vapor pressures less than saturation pressure, the surface is actually hydrophobic (repels water). Because of the very high surface-to-volume ratio, the pores of activated carbon will fill with water because of capillary forces. However, carbon is excluded from this list because it will preferentially adsorb practically every other chemical species before it absorbs water. This is why activated carbons make such excellent water filters. Isotherms depicted for activated carbon and water were measured with "pure" material. After any significant atmospheric exposure, carbon's capacity for water will be seriously degraded, eventually losing any significant capacity.

2. Alumina

Aluminas are also referred to as "gels" for the same reasons as the silicates. They are chemically aluminum oxides and hydrides and are manufactured in much the same ways as silica gel. Generally speaking, the aluminas do not possess the ultimate sorption capacity of the silicas, but they are refractory in nature and are therefore able to withstand higher-temperature environments without damage.

3. Zeolites

Zeolites fall into two categories, natural and synthetic. The natural zeolites are minerals that are mined in much the same manner as salt. The sediment beds of ancient bodies of water are the most common locations for these deposits. Synthetic zeolites are, as the name implies, manufactured materials. The characteristics that relate the natural and the synthetic materials are their chemical and structural similarities. Zeolites are aluminous silicate materials. Their crystalline structure is cage-like; the cage structure forms the sites for preferential water sorption. It is this cage-like structure that also forms the basis for the other designation of zeolites, which is the term "sieve." So-called molecular sieves are synthetic zeolites that have been engineered to possess a specific dimension of the cage. When this dimension is controlled, certain molecules will fit inside and others will be too large. This results in the effective separation of gaseous species.

4. Hydratable Salts

Hydratable salts are a special class of solid desiccants. Generally metal halides, these materials typically experience a transition between solid and liquid phases. Salts that have soluble hydrates are called congruent salts. If the desired desiccant material is a solid, then an incongruent salt would be desired. Hydratable salts, existing as solids, are commonly used in applications where a water vapour pressure that is lower than is possible using liquid is desired. The salt will transit between the anhydrous state and the multiple hydrates state. Lithium chloride is the most common hydratable salt material used. Other hydratable salts are aluminum and copper sulfate, calcium chloride, and lithium bromide.

5. Mixtures

Using mixtures of desiccants is another common method of developing desiccant materials that have the desired sorption properties. For example, some desiccants have large total uptakes for moisture, but are not able to achieve very low humidity levels. Other materials may have marginal moisture uptake, but are capable of achieving extremely low humidity levels. For example, lithium chloride has an unparalleled capacity for moisture absorption at high relative humidity, but below 10% RH, its moisture absorption is negligible. Combining that desiccant with silica gel, which has a larger capacity at low humidities, can provide adequate moisture capacity throughout a wide range of operating conditions. For best performance, desiccant mixtures are selected such that both desiccants can be reactivated at similar temperatures.

6. Liquid Desiccants

For the few office buildings with HVAC systems that are integrated with desiccant cooling technology, liquid lithium chloride was used almost exclusively as the desiccant material. Somerset Technologies, Inc., has a series of dehumidification products with lithium chloride solution as the desiccant. Their catalog provides a detailed description of lithium chloride solution properties. Calcium chloride brine and sodium chloride brine can also be used as liquid desiccants or even be considered as secondary coolants. Ethylene glycol solutions have been used by Niagara Blower Co. for many years on commercial refrigeration for no-frost units. They were used on air conditioners, as well. Test results indicated that the antibacterial effectiveness of glycol solutions is excellent.

VI. MATERIAL USED FOR EXPERIMENT

- **Silica gel**

Silica gel is a chemically inert, non-toxic material composed of amorphous silicon dioxide. It has an internal network of interconnecting microscopic pores, yielding a typical surface area of 700-800 square meters per gram; or, stated another way; the internal surface area of a teaspoon full of silica gel is equivalent to a football field. Water molecules are adsorbed or desorbed by these micro-capillaries until vapor pressure equilibrium is achieved with the relative humidity of the surrounding air. Silica gel was patented in 1919 for use in the adsorption of vapors and gases in gas mask canisters during World War I. During World War II, it was commonly used as a dehydrating agent to protect military and pharmaceutical supplies, among a number of other applications. Its use as a buffering agent to control RH within the mid-range rather than as a desiccant is a unique to museum applications.

- **Titanium Silica Gel**

Titanium silica gel is an adsorbent. Water is attracted and held to the walls of many fine pores within the material. Munters has developed a patented method for manufacturing titanium silica gel in Honey Comb wheel form, which results in a strong and stable structure, yielding ideal drying performance in a wide range of applications.

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(a) (b) (c)

Fig. 1 Desiccant Materials Used (a) Silica Gel (b) Magnesium Sulphate (c) Calcium chloride

VII. EXPERIMENTAL SETUP

- **Base Stand:** This is made up of square tube and sheets this is painted specially with powder coating. All equipment's are mounted on base stand.
- **Air conditioner :** the air conditioner working on simple vapour compression cycle consists following items
- **Compressor:** the compressor is used for pumping the refrigerant through the system it is hermetically sealed type having capacity of 1 ton.
- **Condenser:** the function of condenser is to convert high-pressure vapour into high pressure liquid refrigerant. It is air cooled finned type condenser. A fan is used to force the over the condenser.
- **Expansion device (capillary tube):** the function of expansion device is to reduce the pressure of liquid R22 refrigerant. When the liquid refrigerant passes through the capillary; due to throttling its pressure as well as temperature decreases.
- **Evaporator:** it is refrigerator or actual cooler where the cooling air is required. Heat is removed from air flowing over evaporator by the low temperature refrigerant in the form of latent heat.
- **Cabinet:** this is made up of plywood. It has doors at front with watching window, inlet/outlet duct and recirculation duct of 250*250 mm2 cross sectional area. The doors inside duct can be adjusted for partial/complete recirculation of air. This also has heater load bank and evaporator blower.
- **Instruments/parts in control room :**
- **Electrical Air heater with dimmer (4KW):** air heater is provided for additional loading facility. Heat generated is controlled using dimer mounted on control panel.
- **Wet and Dry bulb Thermometer:** the temperature of air measured by ordinary thermometer is known as dry bulb temperature. Using DBT &WBT, we can determine the relative humidity of air. In this system 3 WBT & DBT thermometer are used. One is placed at inlet of the duct, one after the evaporator and one is placed in the control room chamber.
- **Evaporator blower:** the axial fan blower fitted in the chamber sucks air and it flow over the evaporator coil before entering the chamber.
- **Steam Injection Facility:** this is used to inject the steam generated in steamer. Injecting system into control room carries out humidification of air.
- **Pre heater (500W):** it is used to increase the temperature of air flowing over the evaporator.

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Fig. 2 Experimental Setup

- **Measuring Instruments and Data Acquisition System:**

Temp indicator: Multipoint temp. Indicator with 8 point selection switch has been provided to get the temp recorded by sensor at a different point. RTDs (PT100) sensors are used to measure temp. At following point.

T1=Temperature at compressor suction
T2=Temperature at compressor discharge
T3=Temperature after condenser
T4=Temperature after expansion device
T5=Temperature at fresh air inlet
T6=Temperature at air entering the evaporator
T7=Temperature at air leaving the evaporator
T8=Temperature at chamber

- **PT100 sensors (Pencil type & Bulb type):** The temperature at different point in system is measured by using RTDs (PT100 sensors). These are Resistance Temperature Detectors operating on principle of change in resistance with change in temp.
- **Energy Meter:** Digital energy meter mounted on pane measures the power consumes by the compressor. We can determine the power supplied to compressor.
- **HP/LP cut out:** This is used both as low pressure control & high safety cut out. The inlet connection for low pressure is connected to suction side of compressor and inlet connection. For high pressure is connected to discharge side of compressor. When suction pressure drops below the set pressure or delivery pressure goes beyond set high pressure, the power supply of compressor is cut off.
- **Rota meter:** This is a variable area glass tube liquid flow measuring device. The glass is enclosed in M.S. structure with transparent glass at two sides to read the reading. Calibrated scale is mounted in the enclosure. Float is lifted up as liquid flow through a glass tube & lift is proportional to the flow rate.
- **Gauge Pressure (0-500 PSI):** It is a Bourdon type pressure gauge. This is used to measure the pressure at the discharge point of compressor.
- **Compound Gauge (-30 to 150 PSI):** This bourdon type pressure gauge measure both negative as well as positive pressure. This is used to measure pressure at suction point of compressor.

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- Thermostat: During cooling mode the temperature inside the chamber is controlled by the thermostat. When the temperature decreases below set temperature, the supply to the compressor is cut-off.

VIII. EXPERIMENTAL PROCEDURE

- **DESICCANT BEDS**

We made the Desiccant beds for the experiment. The Size of bed is made such that they can easily fit at the inlet of the duct. Area= 250*250 mm^2, Width= 20 mm.

(a) (b)

Fig.3 Desiccant Beds (a) Before Experiment (b) After Experiment

PROCEDURE

The outside atmospheric air is sucks through a blower which is situated at the end of the duct. While passing inside the duct the air is passed through the desiccant bed as stated by condition 1 in fig 4. As the property of desiccant is to absorb moisture from air, the relative humidity of air is going to be decreased and the temperature of air is going to be increased. As per our requirement to cool the air, it is passed over a cooling coil. Cooling coil is nothing but the evaporative coil of a VCR system. Now the dehumidified and cool air is supplied in cabinet where temperature and humidity is to maintain according to requirement.

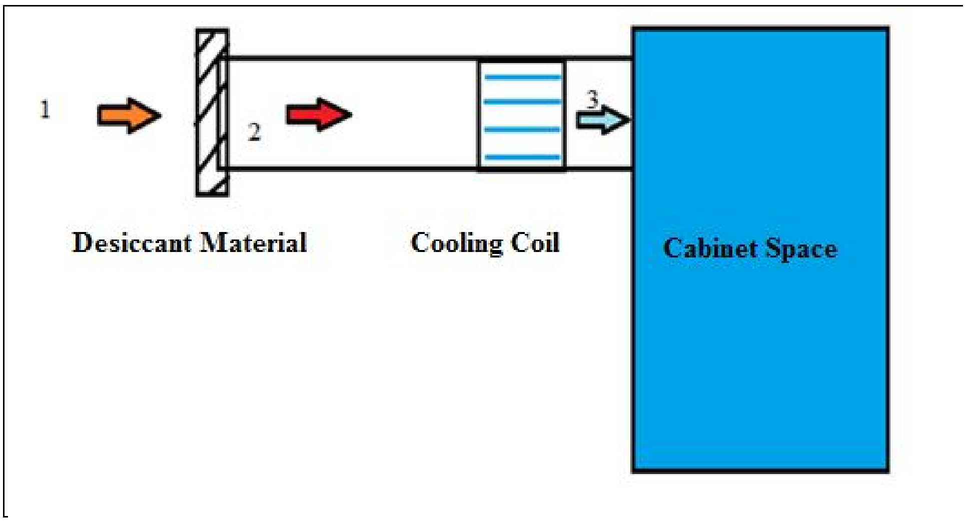

Fig. 4 Experimental Set up with Desiccant Bed

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Where,
1= Before Desiccant Material.
2= After Desiccant Material.
3= After Cooling Coil.

IX. FINITE ELEMENT ANALYSIS

Temperature and the relative humidity inside the cabin for various operating conditions need to be predicted by using the CFD solver ANSYS FLUENT. Three different Desiccant materials were used in the Dessicant Bed. In CFD, Specie Transport modelling without reactions was used for the simulations. The Reynolds Averaged Navier-Stokes equation solver ANSYS FLUENT was used for the project workflow condition at the inlet contained nitrogen, oxygen and water molecules This was modelled in the CFD simulation using the mass flow inlet boundary condition with the specified volume fraction for each specie and the inlet temperature Specie Transport model was selected for to predict the distribution of species and relative humidity inside the cabin The heat removal process in the evaporator was modelled by having the heat source (negative) .The duct outlet was modelled using the pressure outlet boundary condition Standard k-epsilon turbulence model with Standard wall function was employed for modelling the flow turbulence Cabin and the duct walls were modelled using the no-slip wall boundary condition.

- **EXPERIMENTAL SETUP MESHING**

- Block-structured mesh was created for the cabin.
- No of Blocks : 68
- Total no of Cells : 2.2 miillion hexa-hedra

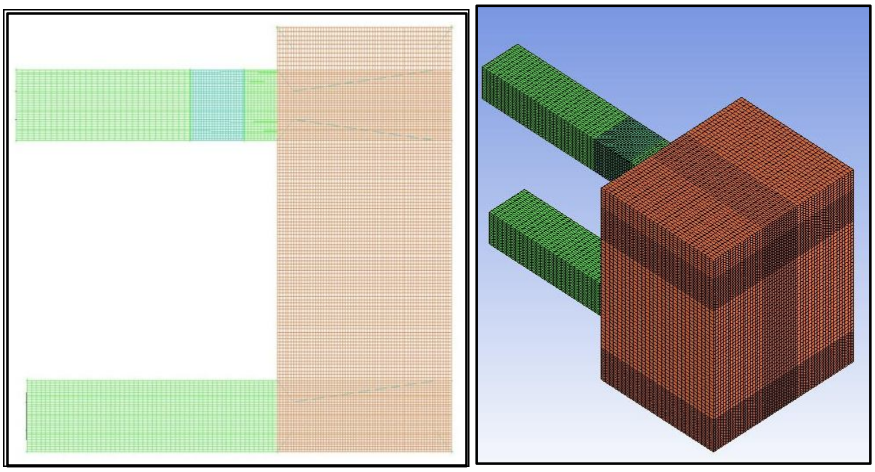

Fig. 5 Meshing of Experimental Setup

X. RESULTS AND DISCUSSION

Traditional vapor compression cooling systems use electrical power to cool and dehumidify air. In contrast, desiccant systems use thermal energy to accomplish the same effect. When properly applied, desiccant systems can save energy compared to traditional systems, and can provide other benefits as well. For example, desiccant systems can:

- Control the humidity of air independently of its temperature, and they can control humidity at very low levels.
- Operate without using Chlorinated Fluorocarbon Compounds (CFCs), identified as contributors to depletion of the ozone layer.

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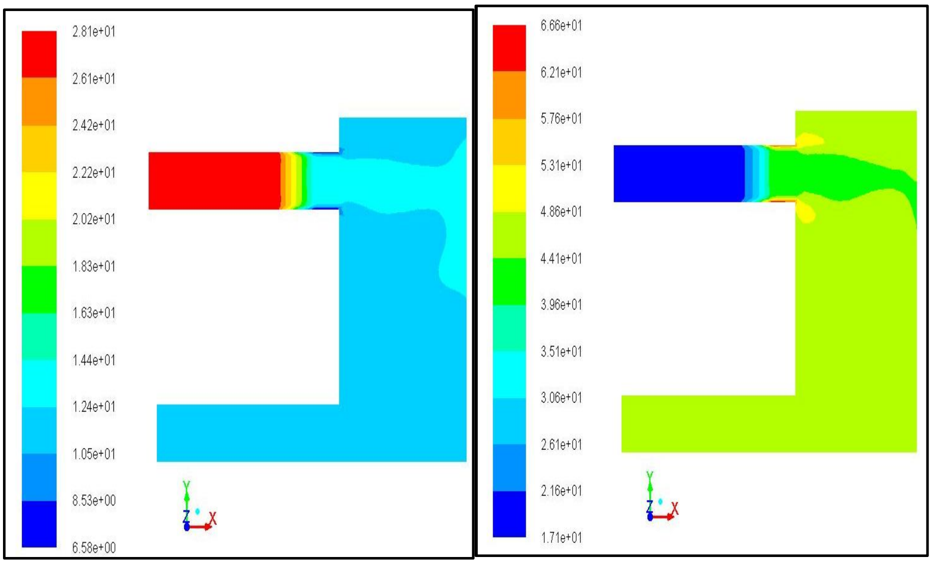
- Balance a large air conditioning energy requirement between several fuel sources-the desiccant system controls humidity using thermal energy and a vapor-compression system controls building temperature.
- Avoid the high humidity which creates indoor air quality problems.
- Avoid wasting energy used to replace materials damaged by water, moisture corrosion and mildew.

Material: Silica Gel



(a) Temperature Variation **(b) Relative Humidity Variation**

Fig. 6 Sample Performance Parameters for Silica Gel Material:

This experimental study is carried out with three different materials. The Fig.6 shows performance parameters such as variation in Temperature and relative humidity as applied for silica Gel during Analysis.

- **ENERGY METER READINGS**

We had done experimental analysis at outdoor air condition as 32^0c and indoor condition as 17^0c.

Table 1. Energy Consumption Readings

Sr. No.	Material	Energy consumed In kw
1.	Without desiccant	0.101
2.	Silica gel	0.05286
3.	Calcium chloride	0.05927
4.	Magnesium sulfate	0.06632

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- **Bar Chart of Energy Consumption**

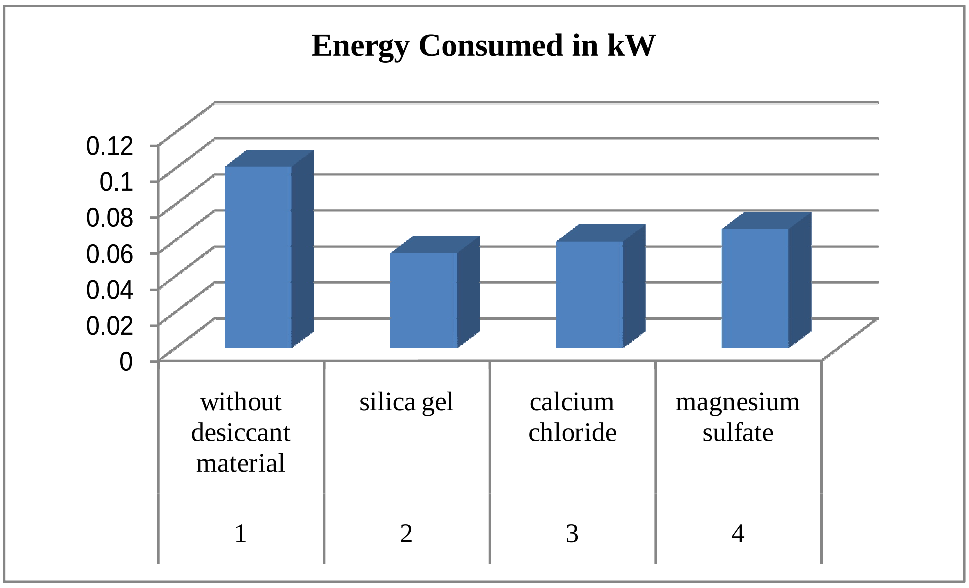

Fig. 7 Energy Consumption Vs Desiccant Materials

The graph shows that the energy consumption by using desiccant material is less than energy consumption without using dessicant**.**

Table 2. Amount of Specific Humidity absorbed by Desiccant Materials in kg/kg of dry air

Sr. No.	Month	Silica Gel	Calcium Chloride	Magnesium Sulphate
1	September	0.0012	0.0002	0.0002
2	October	0.0006	0.0003	0.0001
3	January	0.0007	0.0005	0.0001
4	February	0.0016	0.0018	0.0016
5	March	0.0008	0.0002	0.0006
6	April	0.0016	0.0013	0.0014
7	May	0.0012	0.0010	0.0006

From the above table it is observed that the amout of moisture absorbed by silica gel is greater than other materials.

8.1.2 According to Energy Meter Readings:

Amount of energy saved with the use of desiccant materials

1) Silica Gel = 47.66%

2) Calcium Chloride = 41.31%

3) Magnesium Sulphate = 34.33%

XI. CONCLUSION

Desiccant technology has the potential to make major contributions to energy conservation, improve indoor air quality and to reduce the cost of moisture damage to buildings and products. However, state-of-the-art materials, components and systems are not widely understood or in use in the building industry. Well-coordinated research and development efforts of industry, government and research institutions will be needed to fully realize the benefits of this established, but under-utilized technology. From the experimental results it is concluded that the silica gel is absorb more amount of moisture than other two desiccant materials used. The energy consumption with desiccant enhanced system is less compared to traditional VCR system. The energy saved with desiccant dehumidification is 40-45%

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