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Review

An overview on desiccant assisted evaporative cooling in hot and humid climates

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ABSTRACT

In last few decades due to global warming the temperature of the earth increases continuously day by day responsible for the increased energy demand for cooling the building space. Vapor compression based conventionally used traditional air conditioners consume tremendous energy for cooling the building. So, it is time to search for cooling system which maintains necessary thermal comfort at optimum energy use. Desiccant assisted evaporative cooling system having greater potential for use of renewable solar energy as well as effectiveness in terms of maintaining comfort in hot and humid climate. In the present paper, solid desiccant based evaporative cooling systems are reviewed and it is shown that desiccant assisted evaporative cooling perform better and displayed comparatively lower energy consumption as compared to the traditional air conditioning systems.

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1. Introduction

While the broader use of energy is essential to developed modern society, most primary sources used today are unsustainable and are accompanied with adverse effects on the environment in form of pollution of land and air both. Approximately 81% of the energy is supplied by fossil fuels based energy sources which may deplete in near future. The production of energy from unclean sources like fossil fuels has become a key contributor to increasingly concerning environmental pollution related major issues that include global climate change, acid rain and radioactive wastes. As these environmental threats become more apparent, serious efforts are being made to find innovative ways to save energy and to increase the energy production capacity by use of renewable and sustainable sources like as freely available solar energy and industrial waste heat. The most energy consuming devices on both the commercial and residential sectors are heating, ventilation and air conditioning units (HVAC) as shown in Fig. 1 which used for maintaining indoor thermal comfort [1-3].

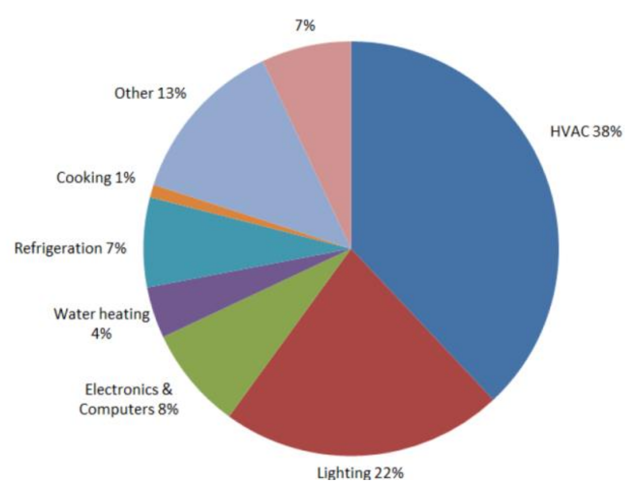

Fig. 1. Distribution of energy consumption in various house hold applications.

There are two conventional ways to condition the air: sensibly and latently. To cool sensibly means to reduce the dry bulb temperature (DBT) of the process air. Latent

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cooling refers to the removal of moisture from the conditioned air. In order to promote a healthy indoor environment, HVAC units must control the sensible and latent cooling demand of the building. Indoor air at elevated humidity levels can promote to the accumulation of bacterial growth inside the building which can be hazardous to the occupants. Oppositely, the indoor air at extremely low moisture level quickly dries the moisture from the occupant's skin, leading to discomfort to the occupants. The key to promoting a healthy indoor environment is to supply air with enough humidity to be comfortable but low enough to avoid problems caused by excess moisture. Therefore, it is important to have efficient control over the humidity level of indoor air; especially inside buildings. The vapor compression cycle used for running the traditional HVAC units can only directly cool the sensible demand of the process air. In order to accommodate the latent cooling load, the temperature of the process air is lowered well below its dew point, allowing water vapor to be removed through condensation of conditioned air. The process of sensibly cooling below the air's dew point results in a reduction in humidity as well as overcooling of room supply air. After the temperature of the process air is reduced, the air is then reheated to meet the temperature desired inside the conditioned space. This process is diagrammatically shown by the black colour line from the state of high temperature to low temperature in the psychrometric chart of Fig. 1. It takes substantial energy to cool humid air containing excess moisture than it does to cool dry. A desiccant assisted cooling system takes advantage of this concept by first dehumidifying the process air before it is moved into the HVAC where it is cooled sensibly. Effectively, a desiccant system lowers air conditioning energy demand by minimizing its latent cooling load. The ideal cooling of process air by a desiccant powered dehumidification and air conditioning unit is depicted by the red colour line in the psychrometric chart of Fig. 2. The dehumidification process of the desiccant cooling is represented by the nearly vertical section of the red colour line. As the air is dehumidified, it rises in temperature slightly before being moved into the conditioning unit. After dehumidification, the process air is cooled sensibly by the traditional cooler to meet the demand of desired temperature of the conditioned space [4-5].

It is necessary to control the humidity of air as recirculated air at extremely low relative humidity quickly dries the moisture from the occupant's skin, leading to discomfort. The key to ameliorate a healthy indoor environment is to supply air with enough humidity to be comfortable but low enough to avoid problems caused by moisture. Therefore, it is important to have efficient control over the humidity level of indoor air; especially inside a home [6-7].

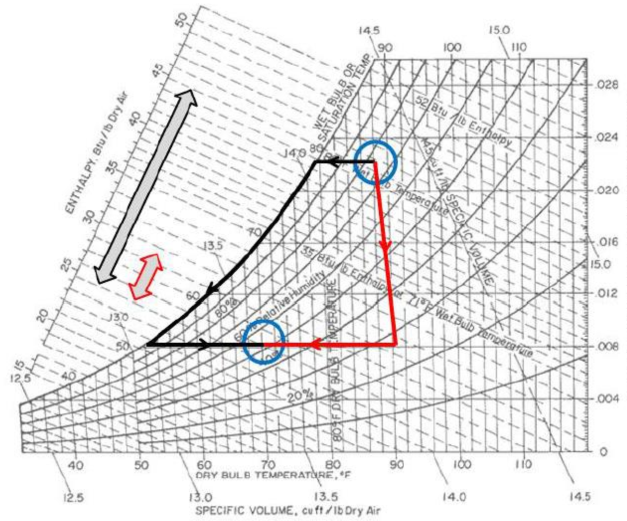

Fig. 2. Comparison between VCR cooling (black line) and desiccant cooling (red line) on psychrometric chart.

The comparison between conventional cooling and desiccant cooling can be elaborated in following table 1 [8-11].

Table 1. Comparison between vapor compression based traditional cooling and desiccant cooling.

Parameters	Conventional cooling	Desiccant cooling
Operating cost	High	Saves 41-48%
Indoor air quality	Average	High
Effect on environment	Harmful	Eco-friendly
Energy source	Electricity	Low grade heat like waste heat or renewable solar energy
Moisture removal capacity	Average	High

Advantages of desiccant cooling can be summarised as follows:

1. Desiccant cooling systems can be operated by use of low grade thermal energy sources like solar energy.
2. Desiccant cooling system is environmentally friendly as it does not use CFC based refrigerants which are responsible for global warming.
3. Over cooling and reheating of conditioned air supply can be avoided by use of desiccant desorption to control the humidity in air.
4. Leakage is avoided as desiccant cooling system operated nearly at ambient pressure.
5. Less prone to corrosion and wetting the supply duct.

A desiccant cooling system consists of passing humid (and warm) air through a desiccant laden dehumidifier rotary wheel for drying and through a cooler for sensible cooling to provide conditioned air. The desiccant material used in the rotary dehumidifier becomes saturated with water and needs to be regenerated with hot air provided by an energy source (e.g., sun, natural gas, waste heat, or electricity). The cost, efficiency, and durability of a desiccant cooling/dehumidification system depend on those of the components used in the system [12-15].

2. Requirement of desiccant assisted evaporative cooling system

In places typically have hot and humid climates such as near to the sea shore, tropical, green rain forest etc. has air-conditioning systems which are essential for human comfort in-connection to effective humidity control. The challenge for air-conditioning systems in especially extreme weather is to control indoor air quality (IAQ) while meeting the building cooling in term of sensible and latent cooling loads effectively. Countries with hot and humid climates can experience extreme temperature and humidity levels to handle the increased moisture load which make the correct design of air-conditioning systems vital. Improper design of air-conditioning systems often leads to poor indoor air quality issues due to lack of proper ventilation air and severe health problems, thermal comfort detriment and higher energy consumption. CO_2 levels in the indoor air often at places like as auditorium, theater, dormitories etc. cannot be diluted enough may affect the human health and productivity of workers in industries. It is well proven that the poor indoor air quality could reduce the performance of office work by 6–9%. Furthermore, airborne pollutants do not escape the occupied air conditioning space and hence affect occupants' health and productivity to major level which cannot be neglected [16,17].

Conventional vapour compression based traditional VCR refrigeration systems are popular amongst designers, builders and famous among the HVAC engineers. This is because the system is simple, well known among designers and commercially available easily. In this traditional air-conditioning system design, the sensible and latent loads of a particular space are being treated by the same air-handling unit in which the dry bulb temperature (DBT) is the only parameter which can get effectively controlled while humidity is separately handled as a by-product of the temperature control. There is no direct control of the humidity despite very high outdoor humidity levels in typical hot and humid climates. Due to this inherent limitation in the system design, the target dry bulb temperature (DBT) is achieved, but the relative humidity is out of the comfort range i.e. 50-55%. Furthermore, this lack of control of humidity can lead to bacteria population and failed to achieve optimal indoor air quality and thermal comfort via traditional VCR based cooling systems results in greater energy use. Therefore, in conventional vapor compression air conditioning systems, comfort conditions can only be provided when sensible heat ratio (SHR) is greater than 0.76. This value can be significantly less, especially for the hot and humid climatic conditions, and thus optimum comfort conditions cannot be fully achieved by the traditional air conditioning. Due to this condition when sensible heat ratio (SHR) is more than 0.76, the thermal comfort cannot be targeted either. Another drawback of the traditional air conditioner is the evaporation of condensate coming out from the unit into the conditioned space due to overcooling which may result in increased humidity levels in the same cooling space. In desiccant cooling technology, major components of the systems are a rotary desiccant dehumidifier and an evaporative cooler. Low-grade thermal energy such as freely available renewable solar energy and industrial waste heat can be used in these systems to regenerate the desiccant dehumidifier while renewable energy such as solar panels can help drive the fans and water pump. This system can operate on a wide range of sensible humidity ratios because of decoupling of sensible and latent cooling loads by effectively handling them separately. Therefore, desiccant assisted air dehumidification and air conditioning system become popular in coming days for the reduction of air humidity and temperature because of its application of renewable energy sources such as freely available renewable solar energy and industrial waste heat. Evaporative cooling systems are highly efficient cooling technologies for cooling in hot climates conditions. However, in extremely high humidity conditions such as those within the range of 75–89%, many investigators propose an integration of the desiccant dehumidifier and evaporative cooler technologies (also known as desiccant assisted evaporative cooling systems). Earlier investigations also reported that the desiccant assisted evaporative cooling systems in four seasonal countries had saved energy of up to 68% in hot and humid summer seasons. Despite its favourable results so far, the desiccant-enhanced evaporative cooling technology is still under the process of development and more intensive research and contribution need to be investigated for the development of this technology. In this paper, a review of desiccant-based evaporative cooling applications is presented focusing on hot and humid climate regions [18-19].In industrial and large-scale applications, solid desiccant dehumidification is the most convenient method for elimination of water vapor from the conditioned space. Many types of solid desiccant materials are commonly used such as silica gel, calcium chloride, zeolite, lithium bromide, lithium chloride and alumina. There are also many silica gel-based composite materials that have been developed which perform better than pure silica gel. Desiccant powered dehumidification can be executed using either liquid or solid desiccant materials as shown in Table 2 [20-22].

Table 2. Types of desiccant materials used in desiccant assisted dehumidification and cooling.

Type	Solid desiccant	Liquid desiccant
Material	Silica-gel	Calcium-chloride
	Hydratable salts	Tri-ethylene glycol
	Alumina	Lithium chloride
	Polymers	Lithium bromide
	Zeolites	

Overall, desiccant assisted evaporative cooling systems can extend the region of applicability of simple evaporative cooling systems. The use of the desiccant wheel with evaporative cooling can be used in buildings with higher wet bulb temperatures or with higher latent heat (like auditorium, supermarkets, dormitories etc.), but it cannot be used in very high thermal load buildings or high thermal load buildings in very humid climates. This system can bring thermal comfort in regional places where the weather condition is moderate. Furthermore, the combination of a desiccant wheel with evaporative cooling can be more efficient in many locations where traditional HVAC cooling systems are not energy efficient.

3. Working of desiccant assisted evaporative cooling system

The role of the desiccant materials used in the solid desiccant based dehumidifier is to absorb the moisture from the supply room air due to vapor pressure difference between hot desiccant and cold room air. The desiccant can be classified as both solid and liquid desiccant materials. Several types of solid materials can hold off water vapor, e.g., silica, polymers, zeolites, alumina and mixtures. Other available liquid desiccants are calcium chloride, lithium chloride, lithium bromide, tri-ethylene glycol, and an equal mixture between calcium chloride and lithium chloride. These liquid desiccants have common general properties, but their requirements cannot be fully described by any single desiccant. These requirements include low vapor pressure, low crystallization point, high density, low viscosity, low reactivation temperature, and economy. The moist air is dehumidified by being brought into contact with strong liquid or solid desiccant, after this to provide sensible cooling to dehumidification process, direct or indirect evaporative cooler units used. When the solution is weakened by absorption of moisture, it sends direct to regeneration process to release the moisture by using an external heat resources. This is called regenerating the saturated desiccant. Thermal energy, at a temperature as low as 47–72°C required for reactivating of the liquid desiccant can efficiently obtained using a solar collector. The typical cycle of the desiccant is made up by three processes as shown in Fig. 3 and Fig. 4 illustrates the difference between conventional air conditioner and desiccant assisted cooling process. The vapor-compression cycle is now the foundation of the HVAC industry and will remain so for many years. The following problems are being addressed through a number of approaches including: (1) more efficient designs for air conditioners, (2) more efficient buildings that require less cooling, (3) the conversion of power generation from fossil fuels to sustainable resources, (4) the development of air conditioners that provide more dehumidification, or latent cooling, more efficiently, and (5) a wider implementation of energy storage technologies. Solutions do exist using only vapor-compression technology, but these solutions will increase the cost for air conditioning. Alternatives to the vapor-compression air conditioner may be better able to meet the growing demand while meeting the new economic, environmental, and performance requirements [23-24].

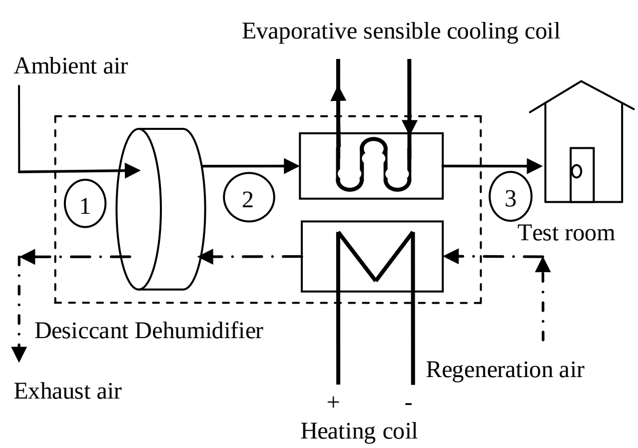

Fig. 3. Working of solid desiccant assisted evaporative cooling system.

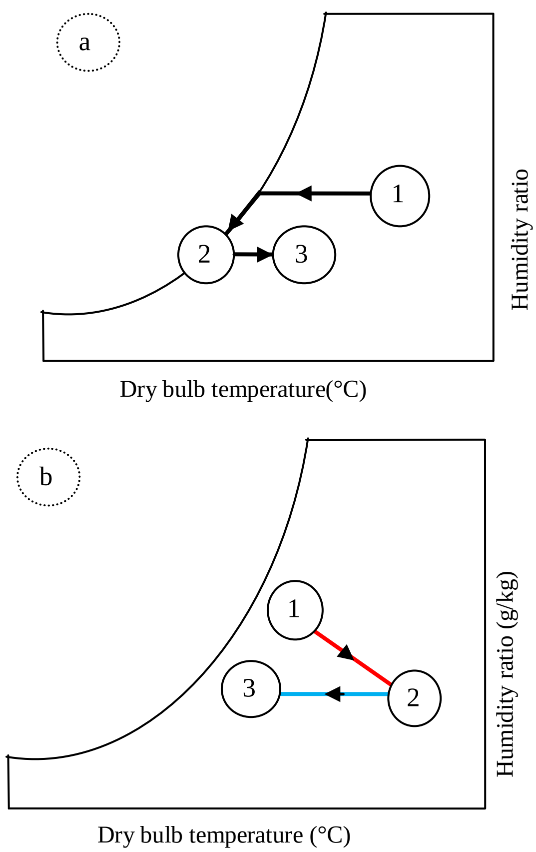

Fig. 4 – Difference between conventional cooling (a) and desiccant cooling (b) on psychrometric chart.

Working of liquid-desiccant system is shown in Fig. 5 the conditioner (or absorber) is the component that cools and dries the process air. As shown in this figure, the conditioner is a bed of structured contact media, similar to the corrugated fill that might be used in a cooling tower. Liquid desiccant is first cooled in a heat exchanger and then sprayed onto the contact media. The desiccant flow rate must be sufficiently high to ensure complete wetting of the media, meaning it should be about 5-8 gpm per square foot of face area. The process air is cooled and dried as it comes in contact with the desiccant-wetted surfaces of the contact media. Heat is released as the desiccant absorbs water from the air, but the high flow rate of the desiccant limits its temperature rise to a few degrees. The regenerator removes the water that the desiccant has absorbed in the conditioner. The desiccant is reactivated by first heating it to raise its equilibrium vapor pressure. The hot desiccant, typically between 55-70°C temperature, is sprayed over a bed of random fill. Flooding rates are again sufficiently high to ensure complete wetting of the media. The hot desiccant desorbs water to the air that flows through the bed. This moisture laden air is typically exhausted to ambient. Both the regenerator and conditioner require droplet filters (also referred to as mist eliminators) to ensure that the desiccant is not entrained in either the supply air to the building or the exhaust from the regenerator. Droplet formation is fundamental to both the spray distributor and the highly flooded beds of contact media used in industrial equipment. Droplet filters can suppress desiccant carryover to parts per billion of airflow, but these filters do increase air-side pressure drops and require maintenance. An interchange heat exchanger (IHX) can be used to preheat the weak desiccant that flows to the regenerator using the hot, concentrated desiccant that leaves the regenerator. The IHX reduces both the thermal energy use of the regenerator and the cooling requirements of the conditioner [25].

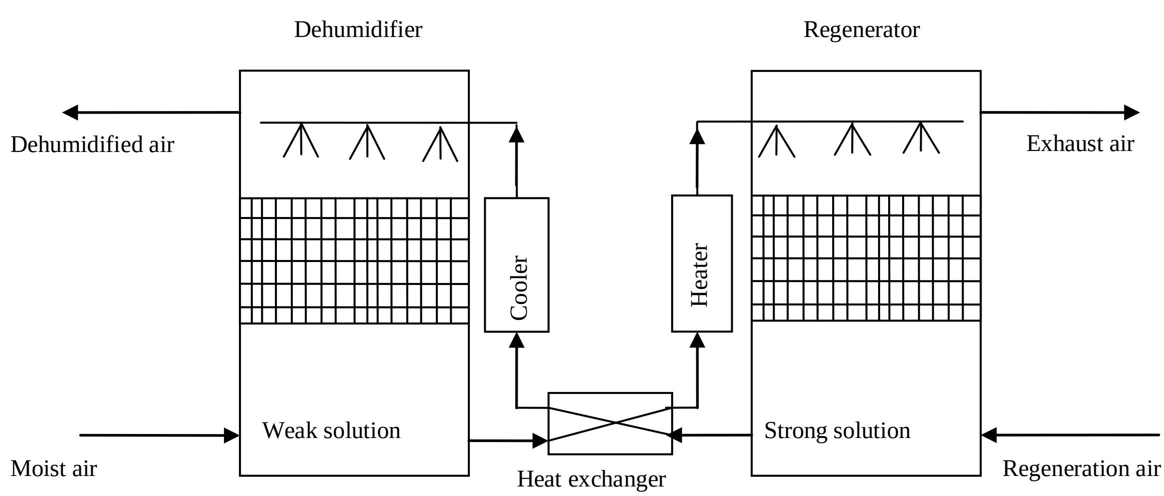

Fig. 5. Construction and working of liquid desiccant cooling system.

4. Conclusion

It has been found that the desiccant assisted evaporative cooling can be operated with supply of primary energy source such as renewable solar energy or industrial waste heat based use of thermal energy for moderate humid climates. The system performance depends on the desiccant material, mass flow rate, air velocity, ambient and demand supply conditions. A standalone evaporative cooling system for a given excess humid operating condition can obtain a certain level of performance and the design needs to be modified to achieve higher performance and economic feasibility by coupling it to rotary desiccant dehumidifier. It has also been found that desiccant assisted evaporative cooling system can be operated at lower regeneration temperature resulted to economic operation as compared to traditional vapor compression cooling at the same dehumidification amount. The moisture removal capacity in the desiccant assisted cooling dehumidification is found to be higher than stand alone evaporative cooling with higher process air flow rate which also improves the system performance. Earlier studies show that the potential of desiccant assisted evaporative cooling in dry conditions is limited but there the evaporative cooling will become an optimum solution rather than combined system. The desiccant assisted evaporative cooling can thus significantly contribute in energy saving and environmental protection.

Nomenclature

CFC	chlorofluorocarbon
DBT	dry bulb temperature (°C)
DEC	desiccant assisted evaporative cooling
EC	evaporative cooling
HVAC	heating, ventilation and air conditioning
IAQ	indoor air quality
IHX	interchange heat exchanger
SHR	sensible heat ratio
VCR	vapor compression refrigeration
WBT	wet bulb temperature (°C)
DW	desiccant wheel
RH	relative humidity (%)

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