CHAPTER 2

DESICCANT DEHUMIDIFICATION IN COOLING AND AIR CONDITIONING SYSTEMS

2.1 Desiccant Dehumidification versus Mechanical Refrigeration

Both desiccant dehumidifiers and mechanical refrigeration systems can remove moisture from the air, so the question is -which type is best suited for a given application? Both desiccant-based and refrigeration-based dehumidification systems work most efficiently when used together. The advantages of each compensate for the limitations of the other.

Refrigeration-based dehumidification systems are more economical than desiccants at high temperatures and high moisture levels. In general, mechanical refrigeration systems are seldom used for applications below 45% RH.

Desiccant-based systems are more economical than refrigeration systems at lower temperatures and lower moisture levels. The difference in the costs of electrical power and thermal energy (i.e. natural gas or steam) will determine the ideal mix of desiccant to refrigeration-based dehumidification in a given application. If thermal energy is cheap and power costs are high, a desiccant based system will be most economical to remove the bulk of the moisture from the air. If power is inexpensive and thermal energy for reactivation is costly, a mechanical refrigeration based system is the most efficient choice.

In some cases, however, the use of a desiccant system can reduce operating costs of the existing refrigeration system. For example; when treating ventilation air in building HVAC systems, the dehumidification of the fresh air with the desiccant system decreases the installed cost of the cooling system, and eliminates deep coils with high air and liquid-side pressure drops. This saves considerable fan and pump energy as well. Table 2.1 is developed using a preliminary energy and economics analysis spreadsheet created for use in screening candidate sites for desiccant technology application. U.S. Army Construction Engineering Research Laboratories (USACERL) developed this screening tool to evaluate potential projects. The primary inputs necessary for this screening include building function, size of area, local utility rates, local weather data, description of current system, and conditioned space requirements. [Initial Cost, Installed] / [Annual Energy Savings-Annual Labor Cost], [40]

Table 2.1 Cost Comparison of Conventional versus Desiccant Systems

Property	HVAC System	Systems with Desiccant
Electricity Rate ($/kWh)	0.068	0.068
Natural Gas Rate ($/therm)	0.35	0.35
Annual Electricity (kWh)	674,327	544,911
Annual Natural Gas (mcf)	0	2,000
Annual Electricity Cost ($)	45,517	36,781
Annual Natural GAS Cost ($)	0	7,080
Annual Reheat Cost ($)	23,933	0
Total annual Cost ($)	69,450	43,861

2.2 Traditional HVAC versus Desiccant Cooling Air Conditioning

Traditional HVAC and desiccant cooling air conditioning progresses diagrams are shown in Figure 2.1 and their thermal processes on the psychometric chart are shown in Figure 2.2. In this two air conditioning system, the fresh air only take the latent heat load in the serving room. For the conventional refrigerant vapor compression system, the fresh air at point 1 has heat/mass exchanger to point 2, from here it is cooled until below its dew point to point 3, in this progress the superfluous moisture is condensed out, and then excess energy is required to reheat it to supply point 4, which mixes with the indoor air to point 5. In this process, overcooling and reheating energy is wasted and more by-product of CO_2 is released. For the proposed effective heat recovery/desiccant cooling system, fresh air from point 1' releases heat/mass effectively to the releasing air until point 2', from here it is further cooled and dehumidified by the cold desiccant to supply point 3'. The treated fresh air deals with the indoor cooling and dehumidification load to point 5', where some air exits out and carries the redundant heat/mass from the entering fresh air until reaching point 6'. This is the novel air treatment circle using less energy to achieve the same air conditioning target. Additionally the special desiccant soaked fiber heat/mass exchanger is utilized in the desiccant cooling system for high recovery effectiveness.

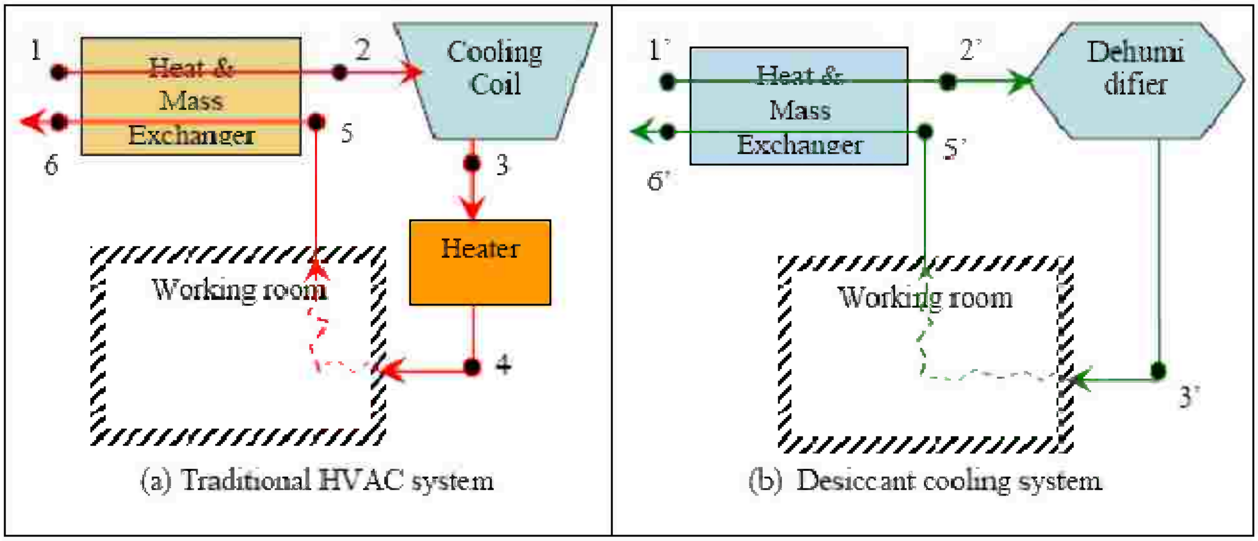

Figure 2.1 Air Conditioning Processes (a) Traditional HVAC (b) Desiccant Cooling with Efficient Heat/Mass Recovery

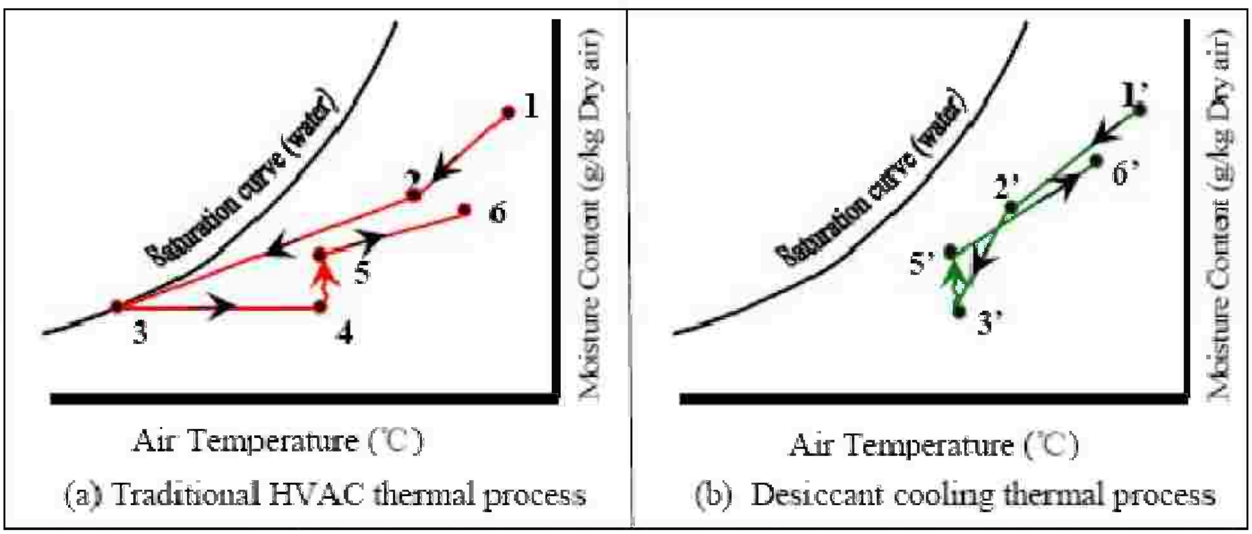

Figure 2.2 Thermal Processes (a) Traditional HVAC (b) Desiccant Cooling with Efficient Heat Recovery

2.3 Principles of Desiccant Cooling

A desiccant cooling system comprises principally three components, namely the regeneration heat source, the dehumidifier (desiccant material), and the cooling unit (Figure 2.3). The efficiency of desiccant system depends strongly on the sensible heat Ratio (SHR).The SHR is defined as the ratio of the sensible heat gain to the sensible and latent heat gain of the space being conditioned [41]. A low value of this quantity means that the total cooling load is predominately the latent load, in which situation desiccant cooling is demonstrated to be effective and economical.

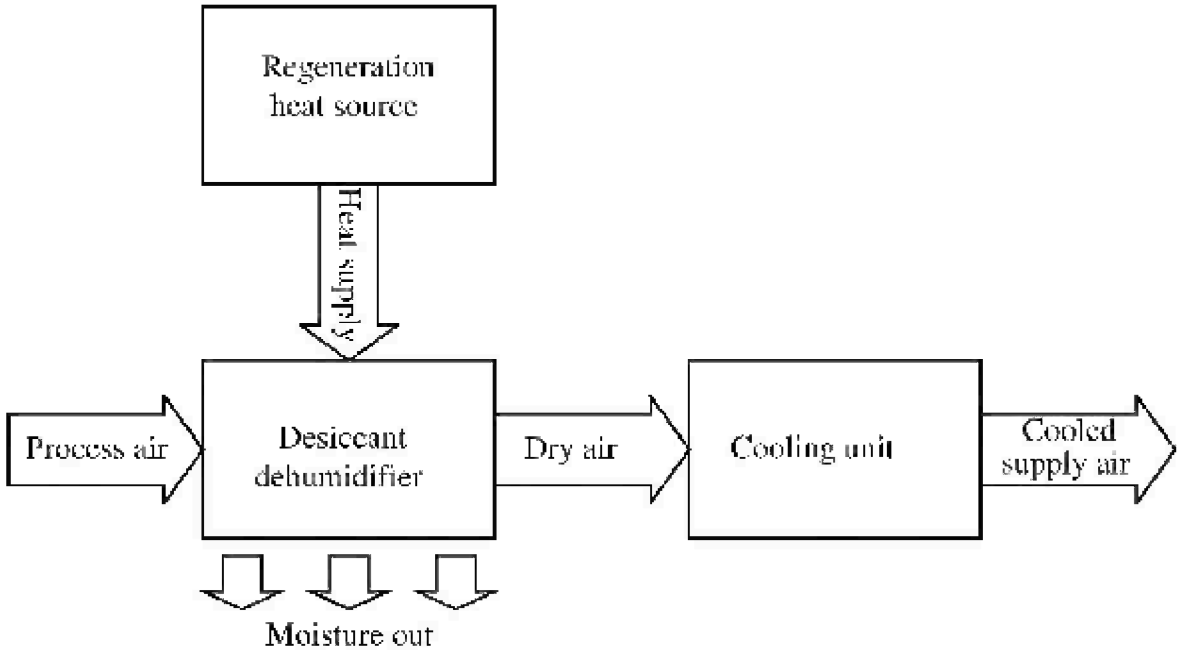

Figure 2.3 Principle of Desiccant Cooling

The possible configurations and/or the composition of each of the three components can vary largely according to the nature of the desiccant employed as described in the following.

2.3.1 The Cooling Unit

The cooling unit can be the evaporator of a traditional air conditioner, an evaporative cooler or a cold coil. The role of the cooling unit is the handling of the sensible load while the desiccant removes the latent load. When a desiccant wheel system is implemented, a heat exchanger is generally used in tandem with it to preliminarily cool the dry and warm air stream before its further cooling by an evaporative cooler or a cold coil, etc. In this case, the heat exchanger together with the evaporator cooler or the cold coil constitutes the cooling unit. Figure 2.4 shows in the form of Psychrometric representation, the use of an evaporative cooler (state 3–state 4) and the cooling coil (state 3–state 4') in tandem with a heat exchanger cooler (state 2–state 3).

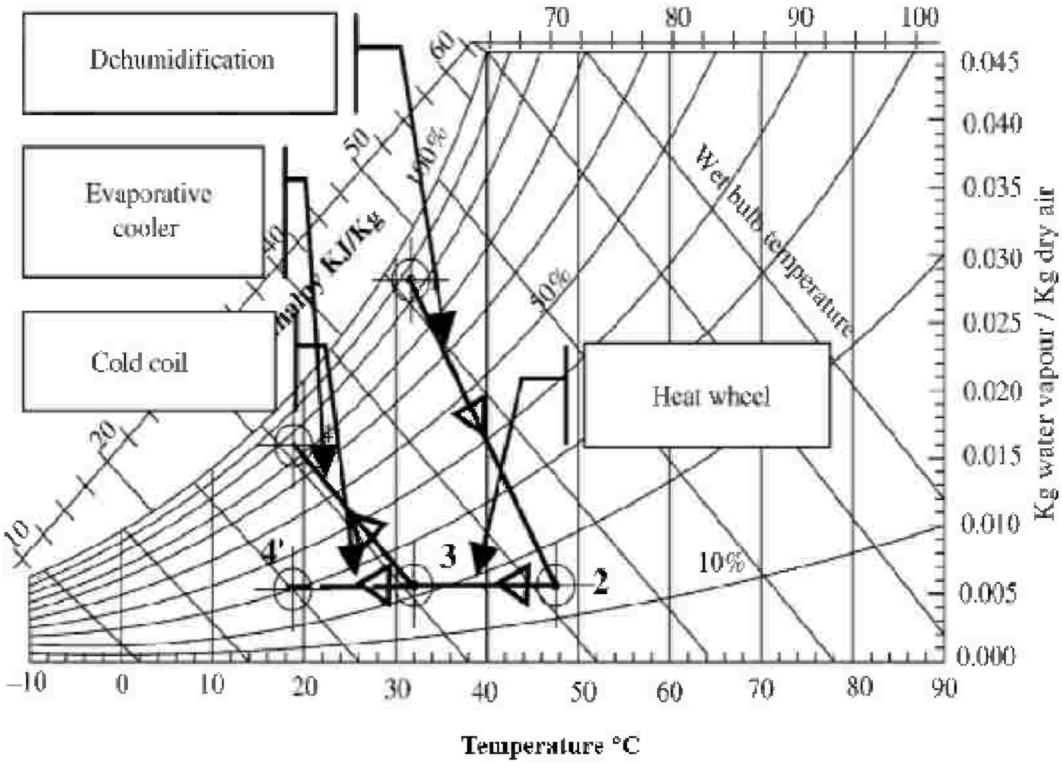

Figure 2.4 Psychrometric Chart Illustrating the Principle of Desiccant Cooling

2.3.2 The Regeneration Heat Source

The regeneration heat source supplies the thermal energy necessary for driving out the moisture that the desiccant had taken up during the sorption phase. Because the thermal energy source is required, a variety of possible energy sources can be utilized. Those include solar energy, waste heat, and natural gas heating, and the possibility of energy recovery within the system [42].

In the case of a liquid desiccant cooling being used, the heat of regeneration is furnished to the desiccant solution inside the structure of a regenerator where a scavenger air stream is concurrently blown to carry away the moisture desorbed under the heating. The scavenger air can also be a hot air stream brought into contact with the dilute desiccant solution inside the regenerator thereby heating it extracting away its moisture. The third component "the desiccant dehumidifier" is discussed in details in the next section.

2.4 Principles of Desiccant Dehumidification

Desiccant Dehumidification is based on the physical process by which water vapor is collected and released by desiccant materials, which can be either liquids or solids. The desorption process, and therefore the desiccant cycle, is driven by heat. When desiccant materials are hot, they give up moisture. The control, capacity, efficiency, and economics of these systems largely depend on the management of thermal energy within the system. A typical dehumidifier unit can be operated on either open or closed cycles. The main difference is that open cycles operate at close to atmospheric pressure, while closed cycles are usually operated at either higher or lower than the atmospheric pressure.

2.5 Desiccant Dehumidifier

A desiccant dehumidifier is a device that employs a desiccant material to produce a dehumidification affect. The process involves exposing the desiccant material to a high relative humidity air stream, allowing it to attract and retain some of the water vapor and then exposing the same desiccants to a lower relative humidity air stream which has the affect of drawing the retained moisture from the desiccant. The first air stream is the air that is being dehumidified while the second air stream is used only to regenerate the desiccant material so that it is ready to begin another cycle.

In general a desiccant dehumidifier is comprised of four major components as shown in Figure 2.5. The component that holds the desiccant which has several types, a fan to move the air to be dehumidified (process air) through the desiccant holder, a fan to move the low humidity air for drying the desiccant through the desiccant holder and a heater to heat the air that will be used to dry the desiccant (regeneration air). The mechanisms of operation of the desiccant dehumidifiers can be classified into two types as follow

2.5.1 Cyclic Type

Some desiccant dehumidifiers use a cyclic type of operation where the desiccant is packed into a container through which the air to be dehumidified is passed. When the desiccant in the container reaches a certain level of moisture content a low humidity air stream is then passed through the container until the desiccant is dry enough to be used for dehumidifying again (regenerated). When two containers are used one can be dehumidified while the other is being regenerated and vice-versa. These types of machines produce varying levels of dehumidification due to the rising moisture content of the desiccant during the dehumidifying stage.

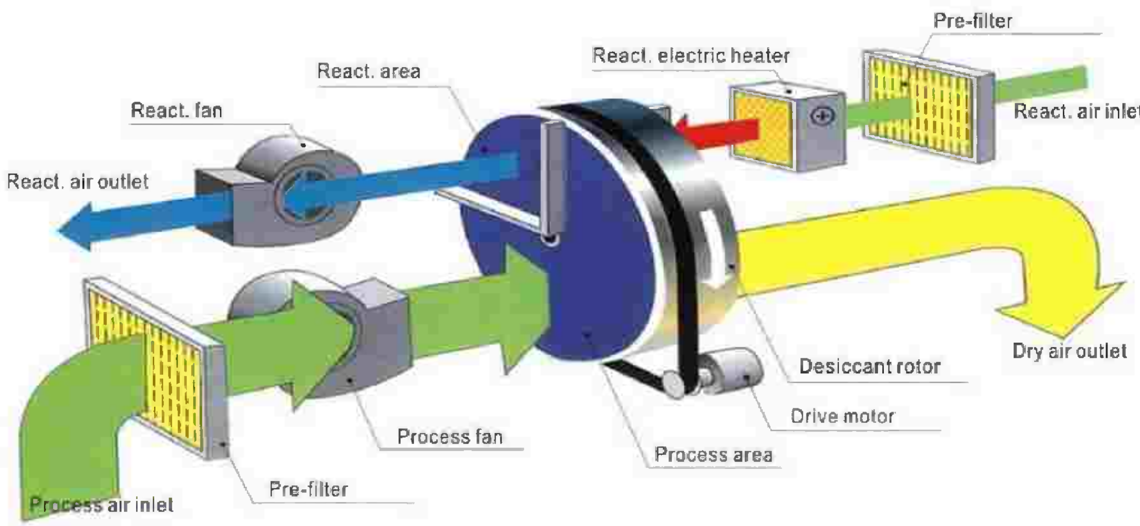

Figure 2.5 Typical Desiccant Dehumidifier Unit

2.5.2 Non-Cyclical Type

There are also non-cyclic types of desiccant dehumidifiers where the desiccant is contained by some type of rotating bed or extended surface wheel. Both process and regeneration air streams are passing through separate sections of the desiccant bed or wheel. The bed rotates slowly (usually less than 20 revolutions per hour). Since the moisture is being moved from the process to the regeneration air streams it is important that these air streams not be allowed to mix or the dehumidification accomplished may be compromised. The effectiveness of the sealing method can have an impact on energy efficiency and on the ability of the machine to produce low humidity air. That is leakage from the regeneration air stream to the dehumidified process air stream will raise the humidity level of the delivered process air.

Desiccant wheel is widely used to lower the humidity of air in the cooling system; it has a good ability to absorb water from air. In the process of air through two desiccant wheels that is latent and sensible state, where in addition to the air becomes dry, the air will also experience an increase in temperature. It is also possible to wash a wheel in water if dust or other particulate block the air passageways. Figure 2.6 shows typical rotary desiccant wheel.

Water vapor comes from moist air stream is adsorbed on the surface of the desiccant material and the outlet stream is less in water vapor content. The desiccant becomes saturated, and needs to be regenerated. A stream of regenerated air is passed across the bed helps to dry the desiccant, and allows it to adsorb more water from the inlet stream.

The dehumidification and regeneration process works at the same time by using desiccant wheel, the regeneration process needs a source of heat to dehumidify the process air stream. While absorbing moist from the inlet air stream it releases heat which means it converts the latent heat into sensible heat and the outlet air stream becomes less moist and warmer, the regenerated stream will exit cooler and moister.

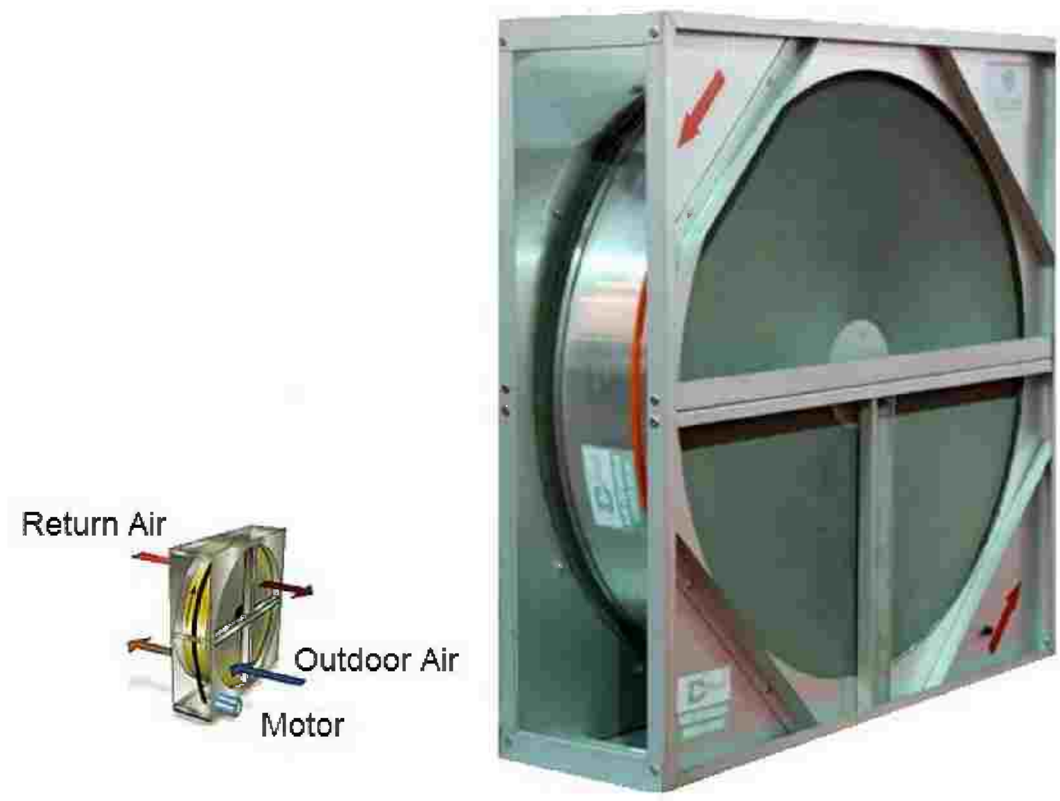

Figure 2.6 Rotary Desiccant Wheel