AN ASSESSMENT OF DESICCANT COOLING CYCLES

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Abstract. *Air-conditioning industry is facing important environmental and regulatory challenges, such as the phase-out of CFCs refrigerants, the requirement of higher ventilation rates and air quality by new design standars. The application of desiccant assisted evaporative cooling cycle has been recognized as a promising technology to suplement or even replace traditional vapor-compression cycles. The use of evaporative cooling cycles is usually restrained to climates with low average levels of relative humidity, however, the development of both liquid and solid desiccant systems has significantly widen the range of application of such systems. Accordingly, the present work aims at describing a variety of arrangements for solid desiccant assisted evaporative cooling cycles and its applications.*

Keywords*: Desiccant Cycles, Adsorption, Air-conditioning.*

1. INTRODUCTION

In face of the economic, regulatory and environmental challenges that have been imposed to the air-conditioning industry, evaporative cooling systems represent a promising solution regarding the ozone layer depletion and the higher ventilation rate standards. The use of evaporative coolers is however limited to areas with low average humidity levels, as it relies on the evaporation of water into the airstream to provide it with the cooling effect. Since the temperature drop of the airstream is usually low (~7ºC), evaporative systems typically have to handle high airflow rates, so as to meet a required thermal load. In any case, the lower the absolute humidity of the airstream, the higher will the cooling capacity evaporative unit. If the air stream can be artificially dried before it is admitted to the evaporative unit, the application of evaporative coolers can be extended to locations with higher average levels of moisture. One way of accomplishing very low levels of humidity is by forcing the airstream through a dehumidifying unit such as a desiccant wheel, which consist of a porous disc strongly impregnated with a hygroscopic material, such as silica-gel or molecular sieves. The fresh air stream is forced through one side of the wheel, experiencing a strong decrease in its absolute humidity as it flows through micro channels. This process is driven by the vapor pressure differential between the process air and the desiccant surface. The material retains the humidity, which is to be purged out by forcing a hot regeneration air stream through the wheel, as depicted in Fig. 1.

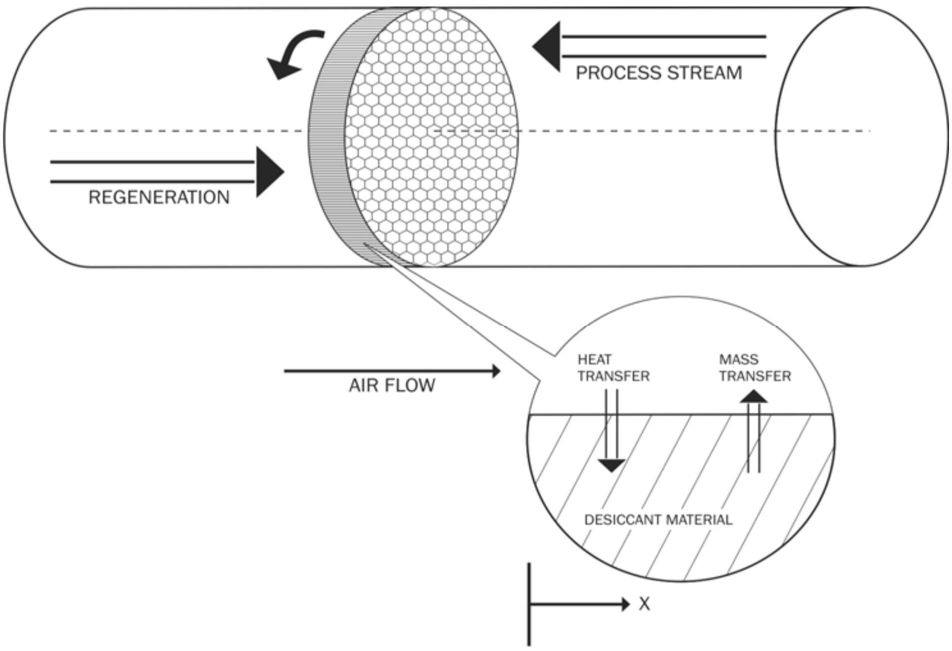

Figure 1: Schematic representation of a desiccant wheel

Once the moisture has been purged, the material is ready to complete the cycle and pick up more humidity. Depending on the adsorptive material and the desired humidity level, the regeneration temperature can be as low as 60ºC, enabling the use of solar energy or low grade waste heat. One of the earliest efforts of modeling air dehumidification by adsorption was made by Trelkheld and Bullock (1966), which used a predictor corrector method to obtain silica gel equilibrium data under adsorption conditions. Maclaine-Cross and Dunkle (1982) proposed a model in which the mass and energy equations were uncoupled under some simplifying assumptions. More recently, many numerical solutions have been provided, predominantly investigating the influence of thermal resistance to heat and mass diffusion within the desiccant material (Niu et al., 2002: Pesararn, 1980; Shen and Worek, 1992). Zhang et al. (2003) proposed a "lumped-distributed" model, which considered mass and temperature distributions only in the flow direction. Their dimensional model shows reasonable agreement with experimental data, and was able to predict some interesting features such as the re-adsorption of water vapor at the beginning of the desorption period at locations far from the heat source. Lima et al (2002) investigated the performance of a desiccant cooling cycle operating in the ventilation mode.

2. PSYCHROMETRIC REPRESENTATIONS

Figure 2 shows the psychrometric representation of an evaporative cooling process. An adiabatic saturation process is carried out, lowering the airstream temperature with a corresponding increase in the absolute humidity. Accordingly, the airstream temperature drop strongly relies on the (low) absolute humidity of outside air. Figure 3 shows that if the latent heat contribution is not very significant or the outside temperature is high, a second evaporator is added to the cycle, and a regenerator can provide precooling of the process air.

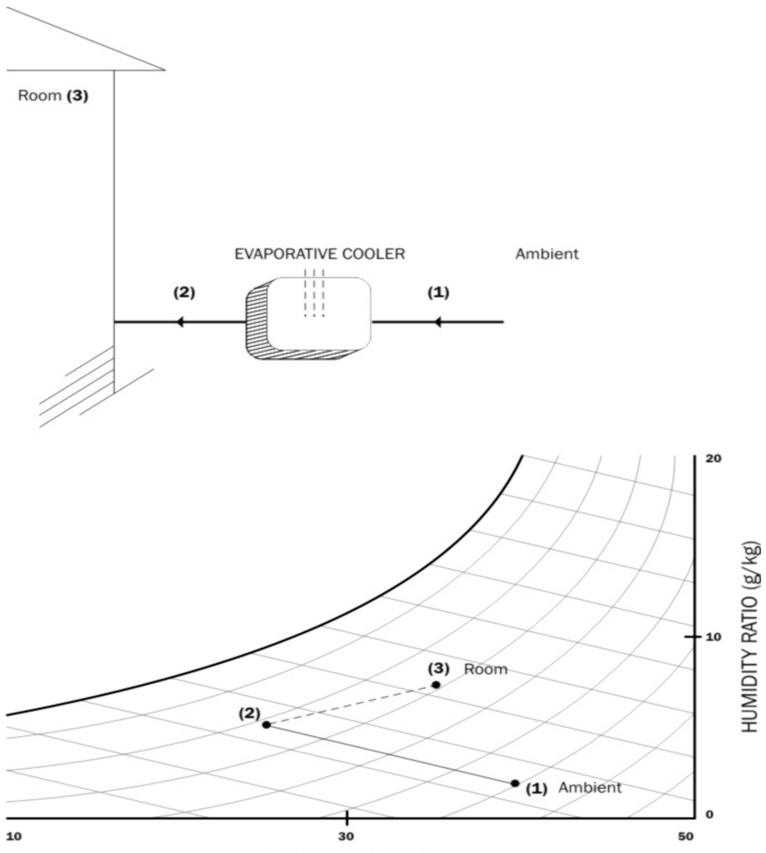

Figure 2: Psychrometric representation of an evaporative cooling cycle

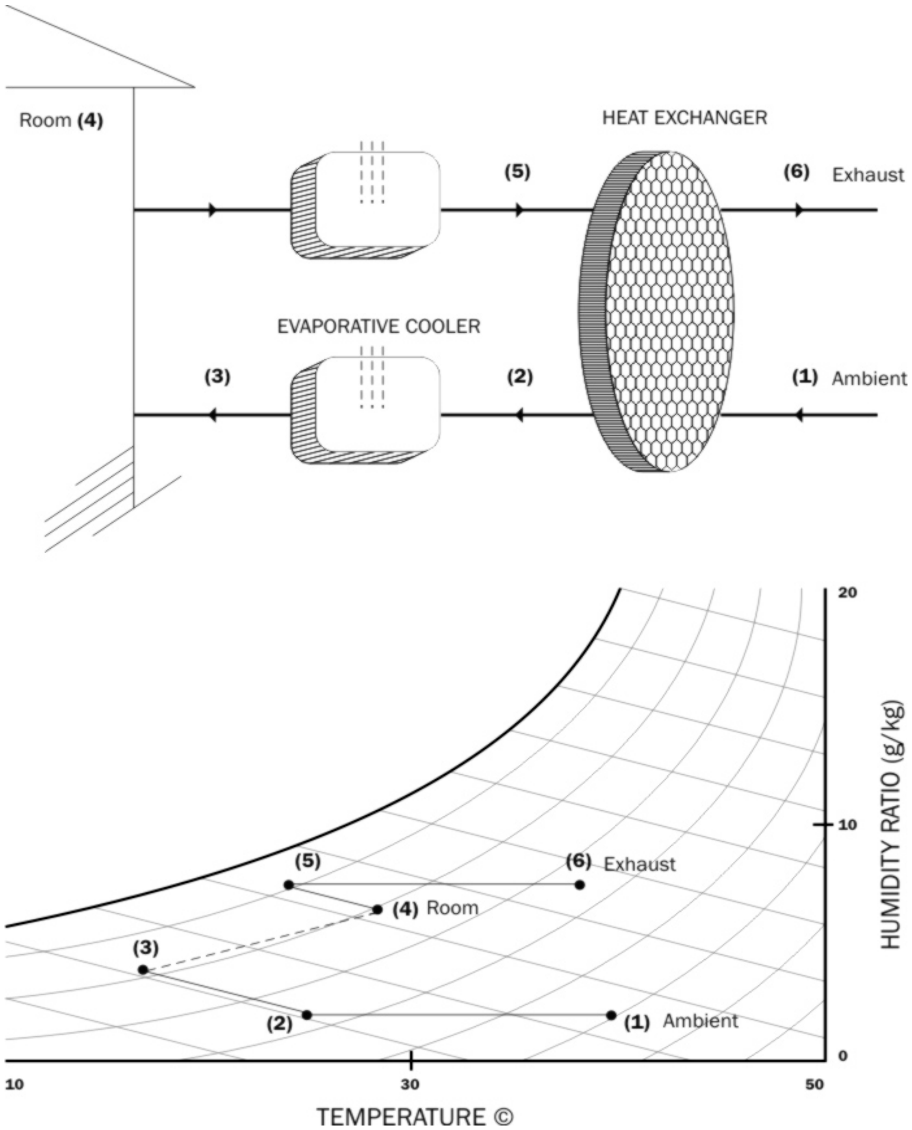

Figure 3: Psychrometric representation of a regenerative evaporative cooling cycle

2.1. Ventilation Cycle

Figure 4 shows the psychrometric representation of a desiccant assisted evaporative cooling cycle, which is often referred to as the ventilation cycle. After it passes through the desiccant wheel, the air stream is processed by a heat exchanger to lower its temperature, before it is admitted to the evaporative unit. The adiabatic saturation process the cools the airstream to the desired comfort condition. If the latent contribution of the thermal load allows it, a second evaporative unit is added at the return stream. After pre-cooling the process stream in the regenerator, the return stream is heated by a thermal source, increasing its temperature to the required regeneration temperature. The return stream is then forced through the desiccant wheel, releasing the moisture from the adsorptive material and dumping it back to the atmosphere. This cycle is recommended for applications with high average levels of outside air humidity.

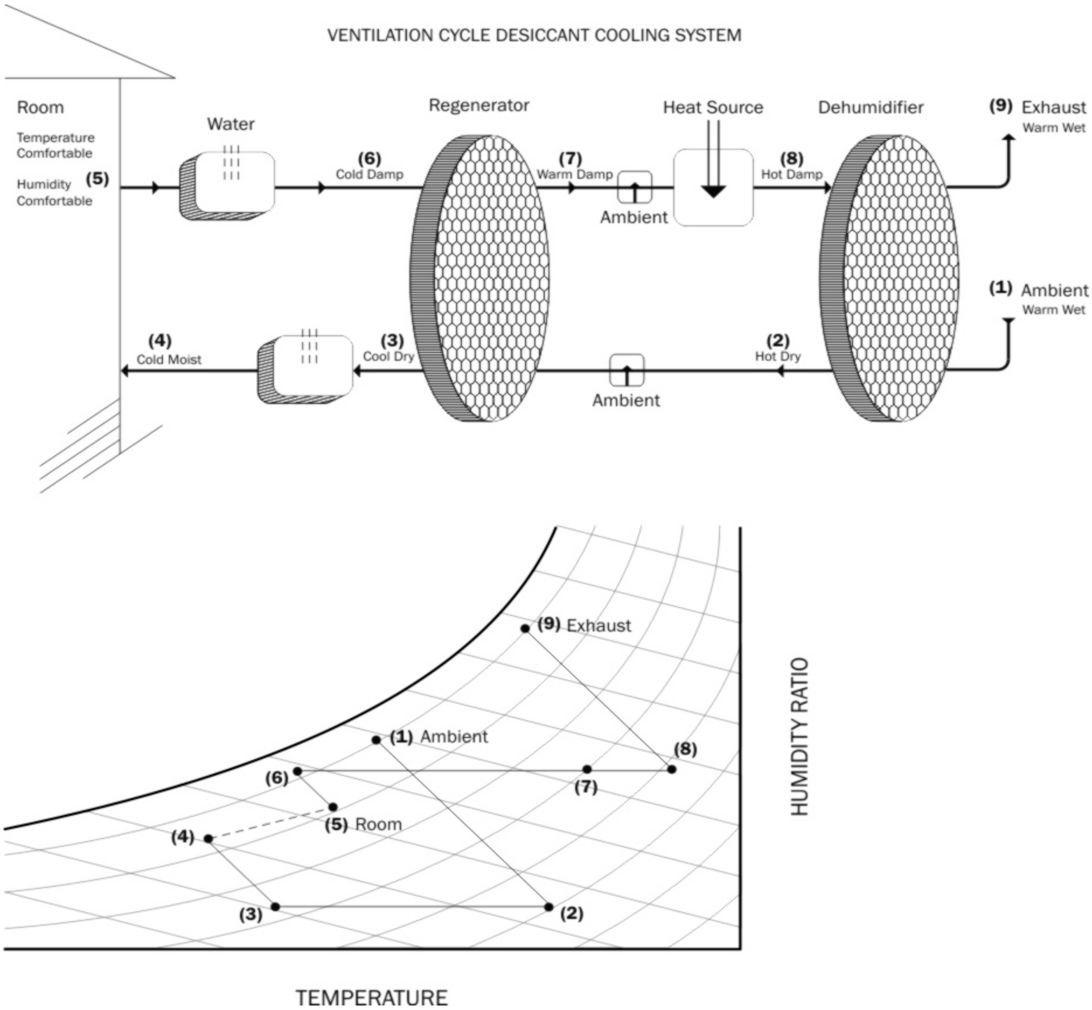

Figure 4: Psychrometric representation of the desiccant cooling cycle (ventilation mode)

2.2. Recirculation Cycle

Figure 6 shows the psychrometric representation of a desiccant assisted evaporative cooling cycle, which is often referred to as the recirculation cycle. In contrast to the ventilation cycle, which provides dehumidified fresh air to the conditioned space, the recirculation cycle continuously processes room air in a closed loop. Accordingly, this cycle is recommended for applications with significant latent heat loads, such as sports arenas. Since the air is continuously regenerated, it has a greater potential for delivering air at a lower temperature. However, the thermal sink for the process air operates at a higher temperature than that of the previous cycle, causing ineffective operation for high regeneration temperatures or high values of the heat released during the adsorption. The air renovation has to be designed as an independent system.

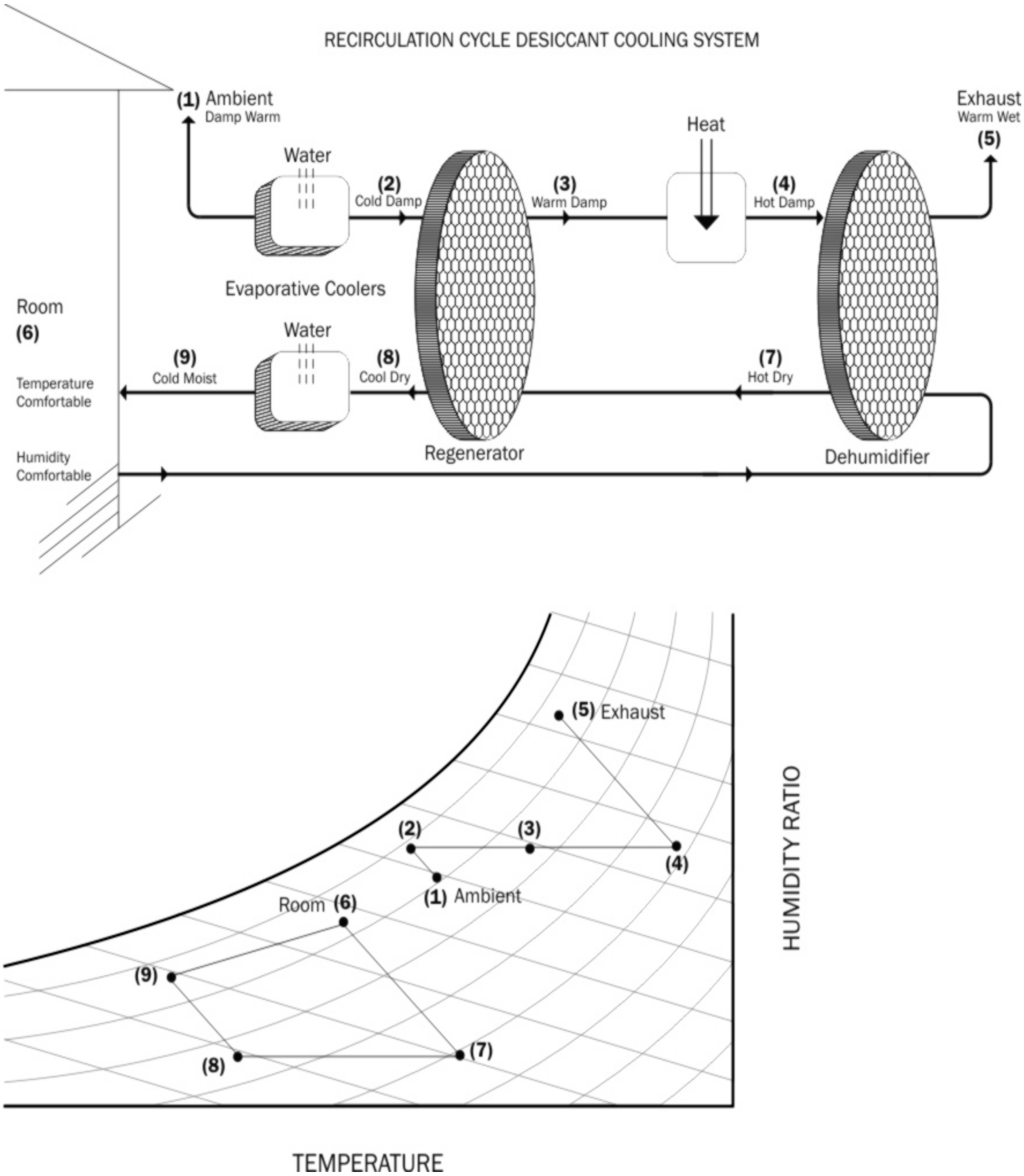

Figure 5: Psychrometric representation of the desiccant cooling cycle (recirculation mode)

2.3. Dunkle Cycle

Figure 6 shows the psychrometric representation of a desiccant assisted evaporative cooling cycle, which is often referred to as the Dunkle cycle. This arrangement tries to combine the two aforementioned cycles, recirculating the process air and cooling it in two stages. Once it is released from the dehumidifier, the process air is admitted into a first regenerator, which cools it to ambient temperature, and then to a second regenerator, which provides further cooling. The objective is to mitigate the increase in the process air temperature as it flows through the desiccant wheel.

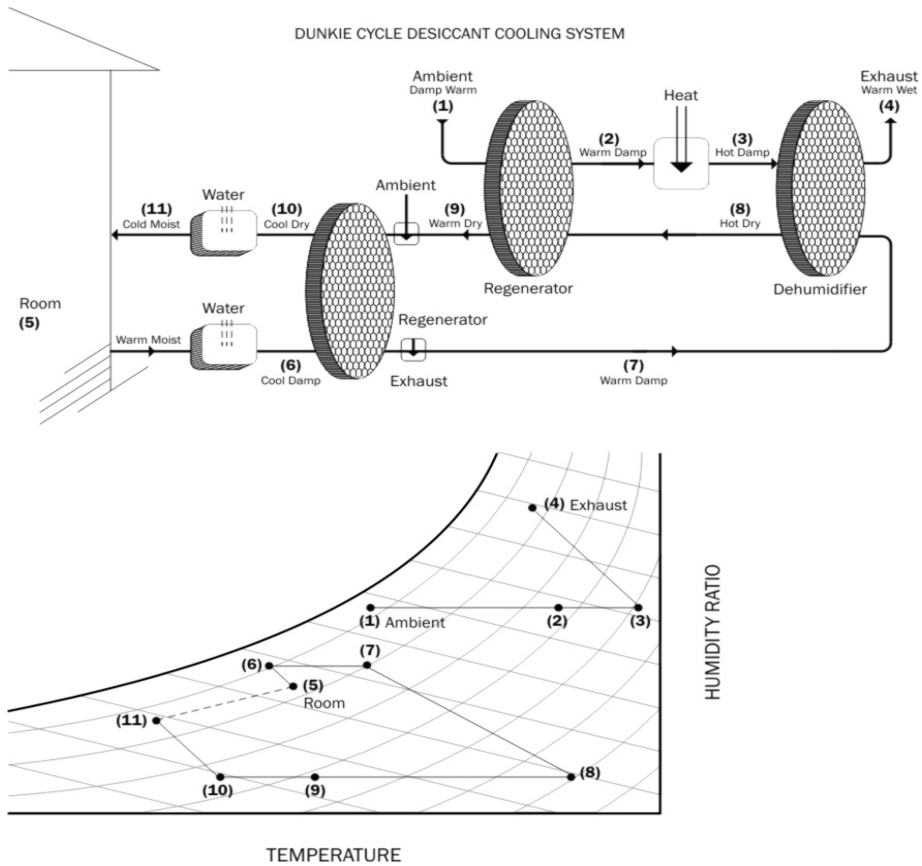

Figure 6: Psychrometric representation of the desiccant cooling cycle (Dunkle´s mode)

2.4. Hybrid Systems

Conventional vapor-compression cooling systems are unable to handle sensible and latent loads separately. Accordingly, oversized compression units are prescribed or are operated for longer periods of time, so as to meet the humidity requirements. As a result, the dry air is cooled beyond the thermal comfort conditions, and has to be heated using electric power. Both practices result in expensive operating conditions. A desiccant unit can be used to remove the excess moisture of the fresh air stream, before it is admitted to the fan coil, resulting in reduced compressor size and eliminating excess chiller capacity. One important application is at supermarket cooling systems; where desiccant units are useful to reduce frost build up refrigerated cases and frozen products, extending product shelf life, as well as the interval between defrost cycles. Humidity control also extends products shelf life and contributes for a healthier environment. New building standards (ASHRAE 62R) require greater rates of ventilation air, increasing the demand for dehumidification products.

3. DESICCANT MATERIALS

A variety of desiccant materials have been used and tested, being the choice of the appropriate material the most important design parameter. Silica-gel is one of the most popular materials, allowing the adsorption of as much as 38% of its own weight. The requirement for the regeneration temperature is moderate; however the adsorptive capacity is reduced for humidity levels below 30%.Molecular sieves are synthetic desiccants derived from sodium, potassium or calcium crystalline hydrated aluminosilicates, and can be custom made so as to contain selected pore size and adsorptive properties. The requirement for the regeneration temperature is high, when compared to that of the silica-gel. Important to observe that an excessively high affinity with water vapor might not be desirable, since the water vapor has to be removed from the desiccant material to ensure cyclic operation (Czachorsy and Wurm, 1997)

4. CONCLUSION

Figure 7 provides a map of the achievable conditions by conventional, regenerative and desiccant aided evaporative cycles. It can be seen that the use of a desiccant unit significantly widens the range of application of evaporative units, allowing its applications even in high humidity levels of ambient conditions.

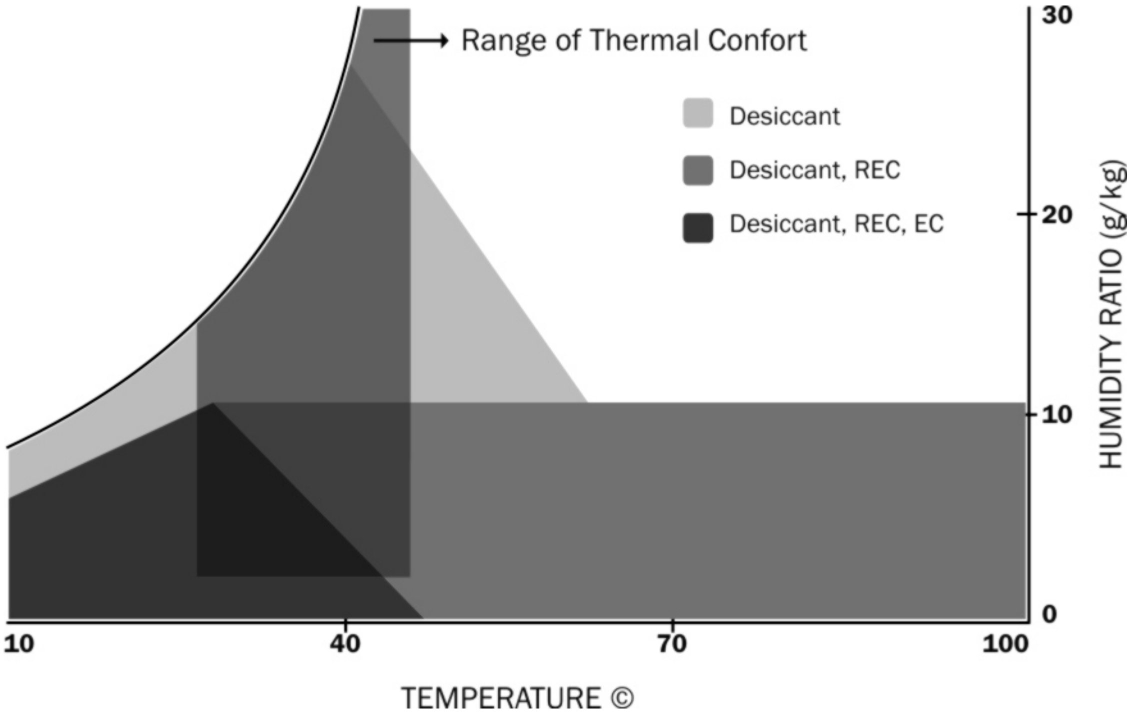

Figure 7: Achievable conditions using desiccant assisted evaporative units

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