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Research Paper

ANALYSIS OF DESICCANT COOLING SYSTEM

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Desiccant cooling systems are heat-driven cooling units and they can be used as an alternative to the conventional vapor compression and absorption cooling systems. Its operation is based on the use of a rotary dehumidifier Desiccant Wheel (DW) in which air is dehumidified. The resulting dry air is somewhat cooled in a sensible heat exchanger Rotary Regenerator (RR), and then further cooled by an evaporative cooler. The resulting cool air is directed into the room. The system may be operated in a closed cycle or more commonly in an open cycle in ventilation or recirculation modes. A heat supply is needed in the system to regenerate the desiccant (natural Zeolite) and a low-grade heat at a temperature of about 60.95. C may be used. The thermal and reversible COPs of an open desiccant cooling system depend on operating conditions of the system. In this paper, we propose a desiccant cooling system with certain operating characteristics for all components. We use this operation as a standard model for calculating thermal and reversible COPs for both ventilation and recirculation modes of the system operation. Parametric studies are performed to investigate the effects of ambient temperature and relative humidity on the various COP terms and cooling load.

Keywords: Desiccants, Desiccant cycle, First and second law analysis of desiccant cooling system

INTRODUCTION

Desiccants has high affinity towards moisture they can draw water vapour directly from the surrounding air This affinity can be regenerated continually by applying heat to the desiccant material to drive off the collected moisture. Several materials are desiccants; that is they attract and hold water vapor. natural fibers, clays ,wood and many synthetics materials attract and release moisture like commercial desiccants do, but they lack of holding capacity of some special desiccant materials. For example, woolen carpet fibers attract up to 21% of their dry weight in water vapor, and nylon can take up almost 6% of its weight in water. In contrast, a commercial desiccant takes up between 10 and 110% of its dry weight in water vapor, depending on its type. and the moisture available in the environment. Furthermore, commercial desiccants carry on

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to attract moisture even when the surrounding air is quite dry.

All desiccants perform in a similar way that they attract moisture from the surrounding until they reach equilibrium with the surrounding air. Moisture is usually detached from the desiccant by heating it to temperatures between 120 and 500 F and exposing it to a scavenger airstream. After the desiccant dries, it must be cooled so that it can attract moisture once again. It always generates sensible heat equal to the latent heat of water vapor taken up by the desiccant, plus an additional heat of sorption that varies between 5 and 25% of the latent heat of the water vapor. This heat is transferred to the desiccant and the surrounding air.

The process of attracting and holding moisture is described as either adsorption or absorption, depending on whether the desiccant undergoes a chemical change as it takes on moisture. Adsorption does not change the desiccant except by the addition of the weight of water vapor, similar in some ways to a sponge soaking up water. Absorption, on the other hand, changes the desiccant. An example of this is table salt, which changes from a solid to a liquid as it absorbs moisture.

Sorbents are materials that have an ability to attract and hold gases or liquids. They can be used to attract gases or liquids other than water vapor, a characteristic that makes them very useful in chemical separation processes. Desiccants are subset of sorbents; they have a particular affinity for water.

TYPES OF DESICCANTS

Desiccants can be solids or liquids, Liquid absorption dehumidification can best be explained by comparing it to the operation of an air washer. When air passes through an air washer, its dewpoint approaches that of the temperature of the water supplied to the equipment. Less humid air is humidified and more humid air is dehumidified. In a similar manner, a liquid absorption dehumidifier contacts air with a liquid desiccant solution. The liquid has a vapor pressure lower than water at the same temperature, and when the air passing over this solution reduced vapor pressure, and then it is dehumidified. The vapor pressure of a liquid absorption solution is directly proportional to its temperature and inversely proportional to concentration (Kanoglu and Yildirm, 2003).

In application, the behavior of a liquid desiccant can be controlled by adjusting its concentration, its temperature, or both. simple heaters and coolers controlled the Desiccant temperature. Concentration is controlled by heating the desiccant to drive moisture out into a waste airstream or directly to the ambient.The absorption process is limited by the surface area of a desiccant exposed to the air being dehumidified and the contact time allowed for the reaction. More surface area and more contact time allows the desiccant to approach its theoretical capacity.

Adsorbents are solid materials with a terrific internal surface area per unit of mass; a single gram can have more than 50,000 ft^2 of surface area. Structurally, they resemble a rigid sponge, and the surface of the sponge in turn resembles the ocean coastline of a fjord. This analogy indicates the scale of the different surfaces in an adsorbent. The fjords can be compared to the capillaries in the adsorbent. The spaces between the grains of sand on the fjord beaches can be compared to the spaces between the individual molecules of the adsorbent, all of which have the capacity to hold water molecules. The bulk of the adsorbed water is contained by condensation into the capillaries, and the majority of the surface area that attracts individual water molecules is in the crystalline structure of the material itself. Adsorbents attract moisture because of the electrical field at the desiccant surface. The field is not uniform in either force or charge, so it attracts polarized water molecules that have an opposite charge from specific sites on the desiccant surface. When the complete surface is covered, the adsorbent can hold still more moisture, as vapor condenses into the first water layer and fills the capillaries throughout the material (Dauo *et al.*, 2004).

All desiccants function by the same mechanism-transferring moisture because of a difference between the water vapor pressure at their surface and that of the surrounding air. When the vapor pressure at the desiccant surface is lower than that of the air, the desiccant attracts moisture. When the surface vapor pressure is higher than that of the surrounding air, the desiccant releases moisture.

Figure 1 shows the relationship between the moisture content of the desiccant and its surface vapor pressure. As the moisture content of the desiccant rises, so does the water vapor pressure at its surface. At some point, the vapor pressure at the desiccant is the same as that of the air and the two are in equilibrium (Ashrae, 1997). Then moisture cannot move in either direction until some external force changes the vapor pressure at the desiccant or in the air.

Figure 1: Desiccant Cycle

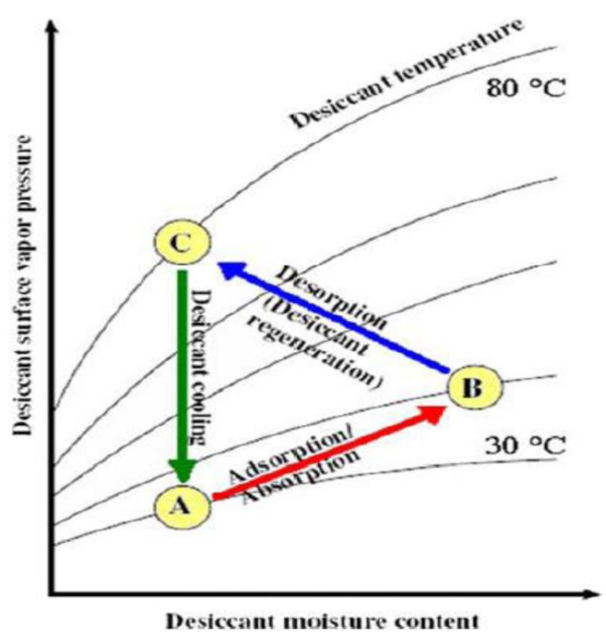


Figure 1 also shows the impact of temperature on the vapor pressure at the desiccant. Both higher temperatures and increased moisture content increase the vapor pressure at the surface. When the surface vapor pressure exceeds that of the surrounding air, moisture leaves (Hirunlabha *et al.*, 2005) the desiccants process called reactivation or regeneration.After the desiccant is dried (reactivated) by the heat, its vapor pressure remains high, so that it has very little ability to absorb moisture. Cooling the desiccant reduces its surface vapor pressure so it can absorb moisture once again. The complete cycle is illustrated in Ma *et al.* (2004) Figure 1.

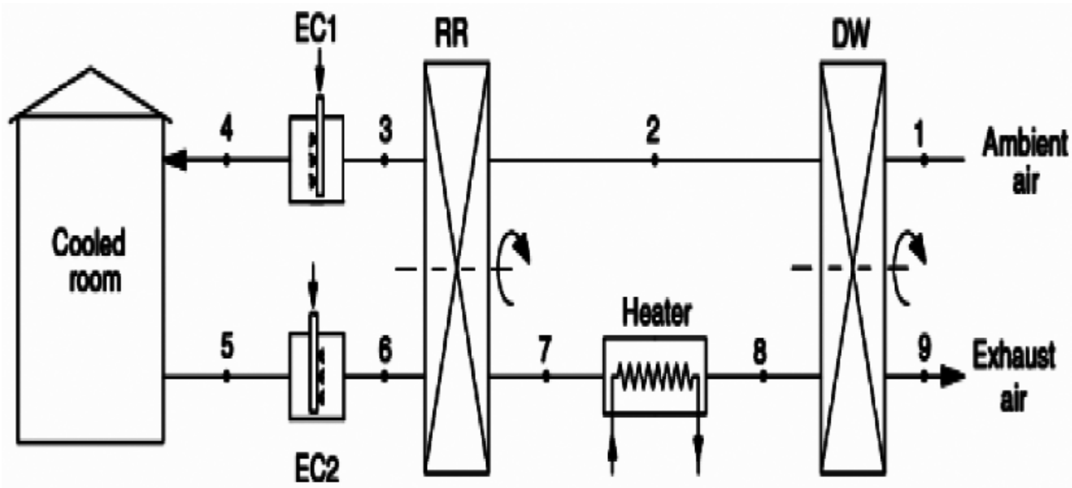
MATHEMATICAL MODELLING

Ventilation Mode

First Law Analysis

In ventilation mode air is first enter in the desiccant wheel where it can dehumidify and heated by the heat of adsorption this heated air is cooled sensibly in the rotator regenerator and then is further cooled in evaporative cooler before enter the room Figure 2. An equal quantity of air withdraw from the room for regeneration (Arora, 2000). This regeneration air is cooled first cooled in evaporative cooler (Konaglu *et al.*, 2004) and then preheated in regenerative regenerator by the warmer air in process line and then external heat is supplied to this air in regenerative line before passing through the desiccant wheel for recharging the desiccant.

Figure 2: Ventilation Mode



An ideal desiccant will dehumidify the air completely so that the specific humidity at the DW exit (Pons and Kodama, 2000).

$W_{Ideal} = 0$ ...(1)

A better relation for the desiccant wheel is effectiveness for specific humidity, which is given by Vanden *et al.* (1988) as:

$\varepsilon_{DW} = (W_1 - W_2)/(W_1 - W_{ideal})$ ...(2)

For an adiabatic desiccant wheel. By energy balance

$(W_1 - W_2)\, h_{fg} = H_2 - H_1$ ...(3)

Where

h_{fg} for water = 2257 kJ/kg

The RR basically a counter flow heat exchanger so

$\varepsilon_{RR} = (T_2 - T_3)/(T_2 - T_6)$ ...(4)

Process air experiences an adiabatic humidification process in the EC following constant wet-bulb temperature line in the psychometric chart.so

$\varepsilon_{EC2} = (T_5 - T_6)/(T_5 - T_{WBT5})$ ...(6)

Similarly the effectiveness of evaporative cooler 1 is given by

$\varepsilon_{EC1} = T_3 - T_4/T_3 - T_{WBT3}$ ...(7)

Noting that the air mass flow rates are equal in the process and the regeneration lines, An energy balance on the adiabatic RR gives

$H_2 - H_3 = H_7 - H_6$ ...(8)

Specific humidity of both process and regenerated air remain constant across the RR.

$W_7 = W_6$ ...(9)

By Konaglu *et al.* (2004) another effectiveness of the desiccant wheel is

$$\varepsilon_{DW1} = (T_2 - T_1)/(T_8 - T_1) \quad ...(10)$$

For sensible heating process

$$W_8 = W_7 \quad ...(11)$$

State 5 is the room state. The external heat supplied to the regeneration air is given by

$$q_{in} = H_8 - H_7 \quad ...(12)$$

The cooling capacity of the system is given by

$$q_{cool} = H_5 - H_4 \quad ...(13)$$

$$q_{regen} = H_8 - H_7 \quad ...(14)$$

$$COP = (q_{cool}/q_{regen}) = (H_5 - H_4)/(H_8 - H_7) \quad ...(15)$$

SECOND LAW ANALYSIS

The cooling system would be reversible if the heat from the heat source were transferred to a Carnot heat engine, and the work output of this engine is supplied to a Carnot refrigerator to remove heat from the cooled space.

$COP_C = q_{cool}/q_{in} = \eta_{th,c}COP_{RC}$ (Vlku and Mobedi)

$$= (1 - T_{amb}/T_{source})\,(T_{space}/T_{amb} - T_{space}) \quad ...(16)$$

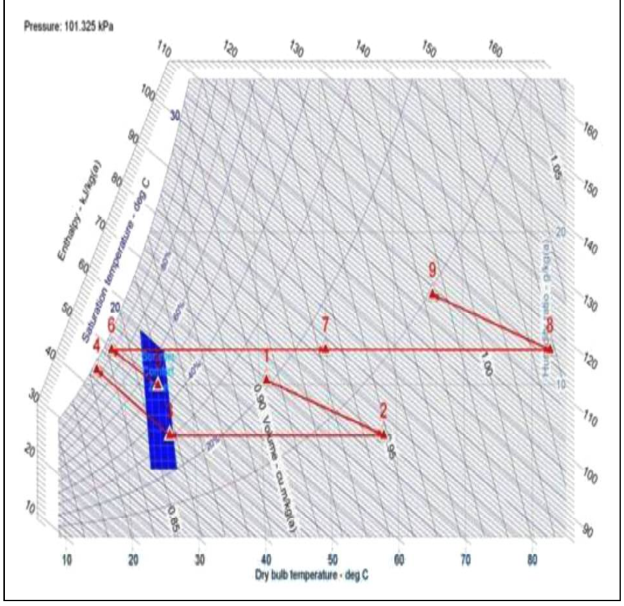
Lavan *et al.* (1982) and Pons and Kodama (2000) investigated the consequences of the open nature of the cycle with different approaches (Table 1). We follow the approach presented by Lavan *et al.* (1982), which is based on using equivalent Carnot temperatures for the evaporator, condenser, and heat source. The reversible COP of the open desiccant cooling systems was expressed using the equivalent Carnot temperatures approach as:

$$COP_{rev} = (1 - T_c/T_s)\,(T_e/T_c - T_e) \quad ...(17)$$

where T_s, T_e and T_c are the equivalent temperatures for the heat source, evaporator, and condenser, respectively. The first one is defined as the ratio of the actual *COP* to the reversible *COP* under the same operating conditions:

$$\eta_{sys} = COP/COP_{rev} \quad ...(18)$$

Figure 3: Psychrometric Chart in Ventilation Mode (Cytsoft Psychrometric Chart 2.2)



RECIRCULATION MODE

In recirculation mode the room air is re-circulated to the process line while the ambient air is drawn into the regeneration line (Figure 4). Here state 1 is room and state 5 is the ambient states opposite.

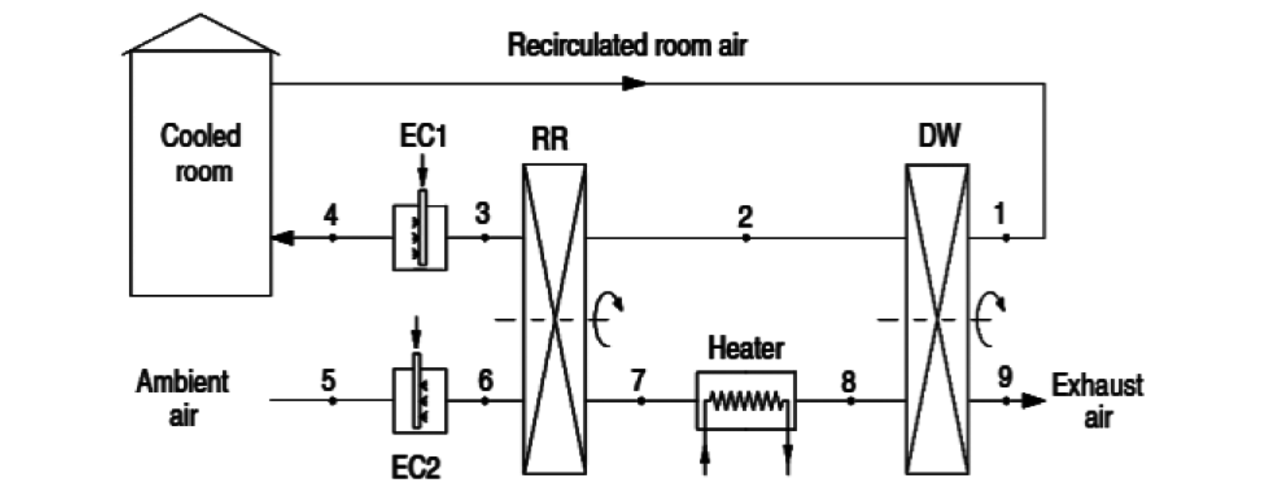
Then the thermal *COP* of this system become:

$$COP = (H_1 - H_4)/(H_8 - H_7) \quad ...(19)$$

the Carnot *COP* of the whole system are

$$W_{out} = \eta_{th,c}q_{in} \quad ...(20)$$

Figure 4: Recirculation Mode



$$q_{cool} = COP_{RC} W_{out} \quad ...(21)$$

$$COP_C = q_{cool}/q_{in} = \eta_{th,c} COP_{RC} \quad ...(22)$$

$$= (1 - T_5/T_8)\,(T_1/T_5 - T_1) \quad ...(23)$$

$$COP_{rev} = (1 - T_c/T_s)\,(T_e/T_c - T_e) \quad ...(24)$$

where T_s, T_e and T_c are the equivalent temperatures for the heat source, evaporator, and condenser respectively.

Figure 5: Psychrometric Chart in Recirculation Mode (Cytsoft Psychrometric Chart 2.2)

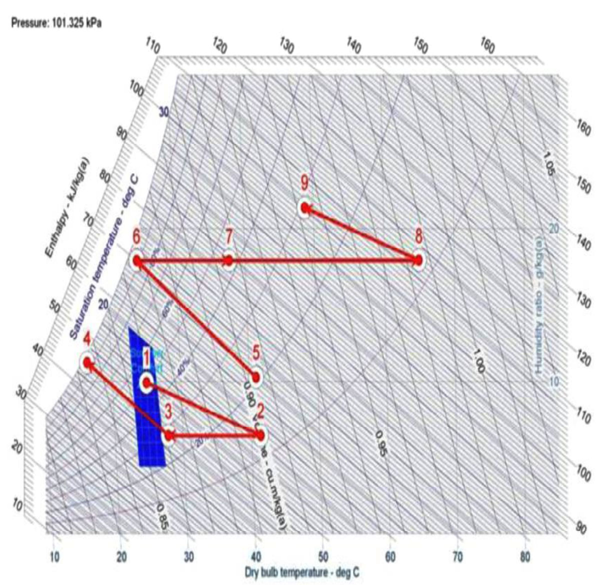


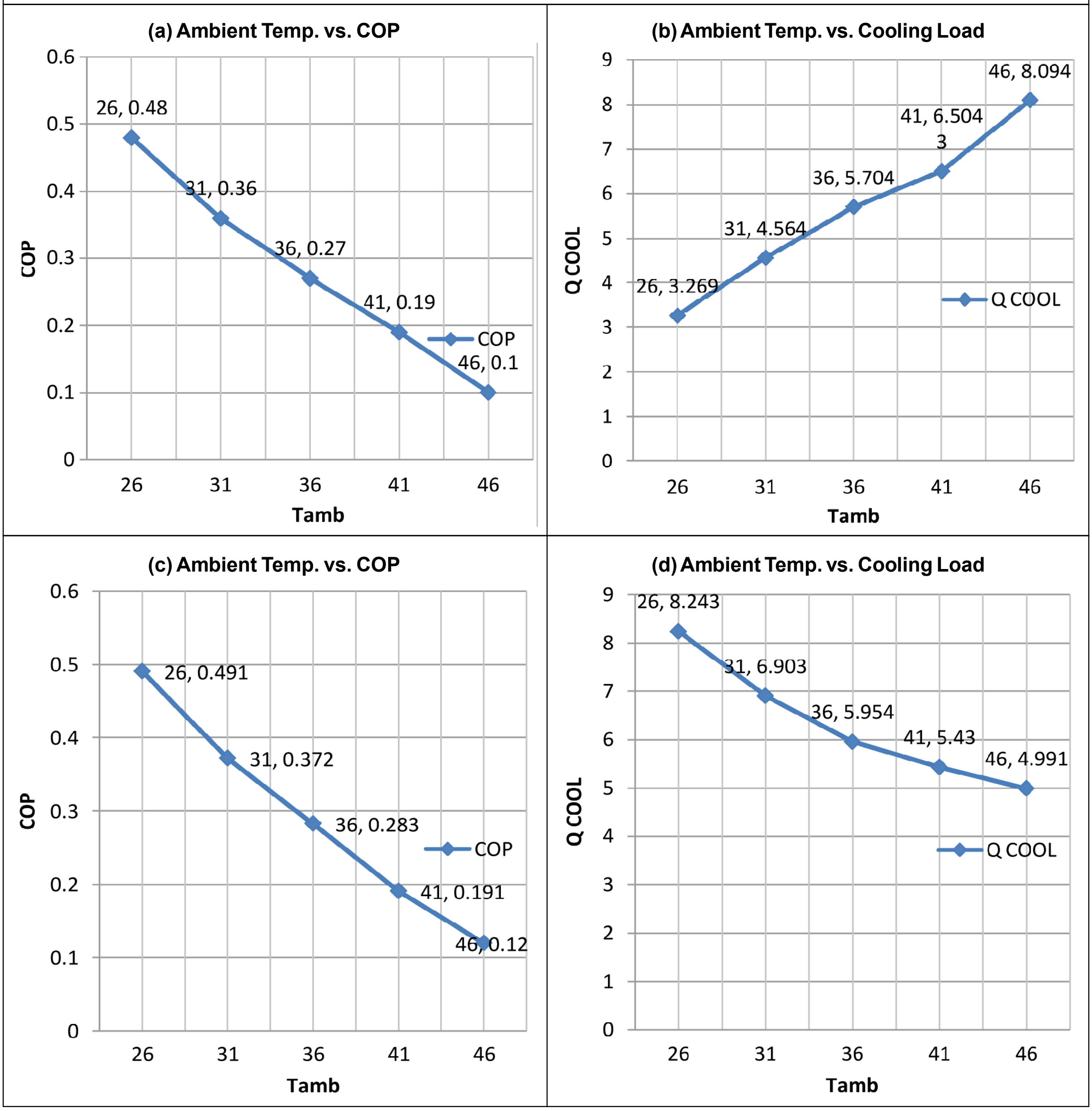
Table 1: Cycle Analysis Parameters

Parameter	Ventilation Mode	Recirculation Mode
q_{cool}	6.5045 kJ/kg	5.432 kJ/kg
COP	0.1916	0.1914
COP_{rev}	1.3128	2.662
T_8	82.6904 °C	64.961 °C
T_s	339.81 °K	324.31 °K
T_c	312.525 °K	303.24 °K
T_e	294.51 °K	296.02 °K
q_{regen}	33.88 kJ/kg	28.374 kJ/kg

RESULTS AND DISCUSSION

- Ambient temperature increases the COP decreases in Ventilation mode.
- Ambient temperature increases the COP decreases in Recirculation mode also.
- As ambient temperature increases cooling load increases in Ventilation mode.
- As ambient temperature increases cooling load decreases in Recirculation mode (Figure 6).
- This can be explained as in ventilation mode the minimum temperature obtained at state 4 was almost independent of the ambient

Figure 6: Graphs at Different Condition



temperature since the ideal DW can completely dehumidify the inlet ambient air and an increased ambient temperature with the same relative humidity means a higher specific humidity at the inlet and this requires a higher regeneration heat to be supplied. In recirculation mode, the regeneration heat supplied remains constant since it is set equal the latent heat removed from the recalculated room process air whose state does not change. The cooling load decreases since a higher ambient temperature corresponds to a higher temp. at state 4.

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