International Journal of Advance Research and Innovation
Vol. 6(2), Apr-Jun 2018, pp. 44-52
Doi: 10.51976/ijari.621808
www.gla.ac.in/journals/ijari

Article Info
Received: 02 May 2018 | Revised Submission: 20 May 2018 | Accepted: 28 May 2018 | Available Online: 15 Jun 2018

Biomimicry for Innovative Air-Conditioning

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ABSTRACT

The intendment of Air Conditioning lies not just only in removing the heat from a confined space so as to produce a state of thermal comfort, but also must focus on Energy Efficient processes, parroting the similar state of Thermal Comfort. Biomimicry is an emerging field of science that imitates nature and applies such process for scientific technologies. In Biomimicry for airconditioning systems, the requirement for energy efficient processes lies in creating a domain of thermal comfort by a process that would eliminate the necessity for an energy consuming process. Also such bionic inspired systems must be reliable and must not cause further disadvantages. In such a scenario, this work focuses on three main bio-inspirations; A Termite Mound inspired convection currents, Blood Flow in Penguins inspired counter flow heat exchanger system and the behavior of an insect Brown Dog Tick that secretes an interesting hydrophilic chemical that could be used for dehumidification. Various happenings in the three biological processes have been discussed and the feasibility of such processes to be implemented in technological behavior has been discussed.

Keywords: *ThermalComfort;Biomimicry; Bionic; Hydrophilic.*

1.0 Introduction

Air Conditioning systems play a vital role in the energy behavior of any building. Researches have estimated that, 65% of the energy consumed by the building industry is for Heating, Ventilation and Air Conditioning (HVAC) [1] and its allied activities. Hence energy efficient HVAC Systems are the necessity for the hour without any compromise in the operational efficiency and the air quality management.

Energy efficient buildings will definitely be a backbone in the development of any country. Several systems are being developed to aggrandize the energy efficiency in buildings. Systems like Unglazed Solar Thermal Facades [2], Phase Change Materials in Buildings [3], Integrated control of natural ventilation and HVAC systems [4], Utilizing Renewable Energy Sources for Air Conditioning Systems [5] will definitely prove energy efficient. In such a progress in technology, the field of biomimicry is gaining interest.

Biomimicry helps designers to apply concepts and mechanisms that naturally happen around to a complex technological process that would indeed solve tedious problems. Nature is a source for many designers and architects as the evolution of it takes many forms, and happenings. Mother Nature has provided human beings with a myriad source of inspiration to ponder with. Biomimicry is classified [6] into three categories:

1. Organism level Biomimicry
2. Behavior level Biomimicry
3. Ecosystem level Biomimicry

Gerhard F. Swiegers [7] describes biomimicry to be a reverse engineering from nature. Wright brothers built a flight after getting from the wings of birds. Hence biomimicry for Air conditioning systems will definitely prove energy efficient as well

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as would definitely expound complex phenomena. Several Bionic inspired systems are being developed in many parts of the world. A few notable bionic inspired buildings [8] include

- The Council House, Melbourne
- The Water Cube, Beijing,
- The Esplande Theatre, Singapore
- East Gate Center, Zimbabwe.

It is not just with buildings, several technologies are also now being inspired from biological inspirations. Several bioninc inspired heat exchangers are also being developed that inspires the flow of blood of blood through arteries and veins [9] and such systems are found to be more efficient than conventional systems.

Fig 1: The Esplande Theatre, Singapore Inspired from the Skin of Durian Fruit

A typical termite mound is show in Fig.2. Termite build large mound where they grow fungus which will serve as a primary source of food to the termite. The fungus is grown at the bottom of the mound.

A Termite mound consists of large number of pores on the surface which acts as air vents. The air vents in a termite mound is schematically shown in Fig.3. Termites constantly close and open selected pores and this activity is of utmost importance as it is the source of inspiration for an airconditioning system.

2.0 Termite Mound Inspired Air-Conditioning for Buildings

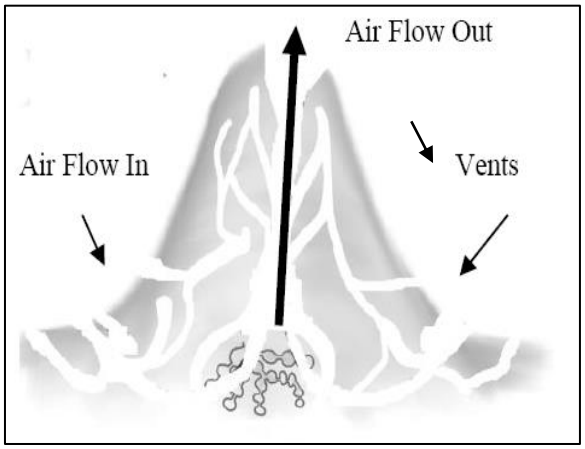
2.1 Architecture of termite mound

Fig 2: A Typical Termite Mound at Coimbatore

2.2 Thermal Behavior of Termite Mound

A Termite Mound was taken into consideration located at Coimbatore.. Temperature Measurement has been carried out using infrared thermometer pointing to the inner of the mound. Temperature inside the mound was reported monthly. The variation in temperature inside the considered temperature mound is shown in Fig.4

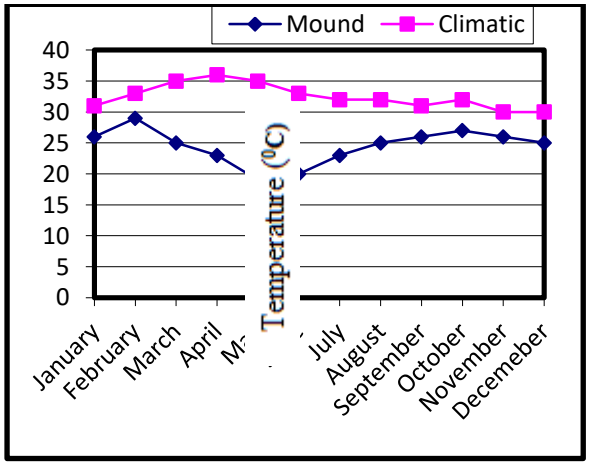
Fig 3: Air Flow in a Termite Mound (Open Mound)



From Fig.4, it can be inferred that, throughout the year, the temperature inside the termite mound remains lower than the climatic temperature of the ambient.

Such a system can be used in hotter parts of the world where the necessity of the air conditioning system will be on sole cooling of the building. Inside the termite mound, convection phenomenon is used to keep the temperature lower than the environment.

Fig 4: Temperature Inside Termite Mound (2018)



Termites constantly close and open certain pores as a regular process throughout the year and this causes air from outside to enter inside the vents and it takes up the heat inside and goes out through the vent at the top.

This phenomenon takes place throughout the year and hence the temperature is maintained lower. This phenomenon can be taken as an inspiration for HVAC systems in buildings.

Air from outside can be circulated to the inner of the building and can be exhausted..

3.0 Biomimicry at East Gate Center, Harare

The East Gate Center at Harare, Zimbabwe is a standing witness for inspiration from Termite Mound.

The Building uses similar Technology in ventilation. The building vents the hot air at the top of the building.

It has fans to drawn in air from the atmosphere at the bottom of the building.

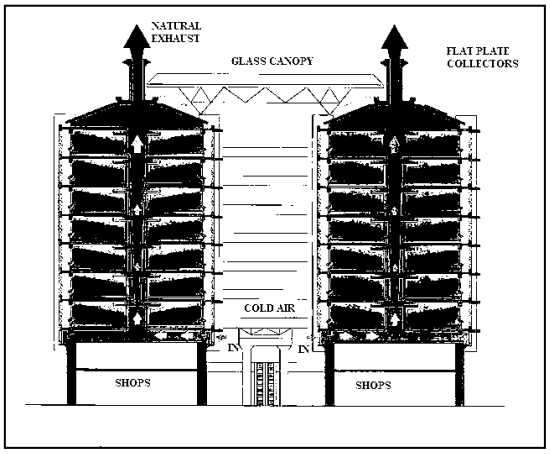
The electric fans are generally used at night to suck in cold air from the atmosphere, expelling hot air out of the building.

This will additionally cool the building during night time. The air flow is shown in Fig.5

Various benefits that are achieved by using such biomimiced system are:

1. A minimum 3^0C temperature difference can be achieved between the outside environment and inside environment
2. The maximum temperature that is recorded indoors is 26^0C.
3. This system is able to save in the building, about 90% energy that is consumed by conventional HVAC systems.

Fig 5: Ventilation at East Gate Center, Harare



Various technical requirements in the biomimicry of Termite Mounds:

1. The Building must be provided with a source of air entry and a source of air exit such that the flow of convection currents in facilitated. Auxiliary systems include fans and diffusers matched with the thermal load of the building
2. The building must be provided with heat accumulation system at each room, such that the hot air is raised up to the heat accumulation system and gets vented out. Due to the density difference between the hot air and the cold air, the hot air rises above the cold air and gets accumulated and from the accumulator must be vented out.
3. Facades and vegetation can be enhanced on the building facing direct solar radiation so as to avoid building from getting heated. This will

further enhance the process of achieving Thermal Comfort.

4. Air quality maintenance systems without any compromise in Indoor Air Quality. Primary
5. include removing area rugs and utilizing compact indoor air quality controllers.
6. Windows of the East Gate buildings are arranged in such a way that minimum heat is transmitted through it in summer. Hence such designs would be preferred and would further increase energy efficiency for buildings attempting the termite biomimicry.

3.1 Comparision of biomimiced system with conventional system

As quoted previously, this system saves about 90% of energy that any conventional air conditioned system when applied to the same building. Thus biomimicry from termite mound proves energy efficient. Further Solar Flat Plate Collectors provided at the top of the first building, will pull down the conventional cost of water heating. Hence this will also eliminate unnecessary space occupied by packaged air conditioning units, Chillers, Cooling Towers and other related accessory components. Conventional Air conditioning systems for building will need to have special ducts to supply cool air, water circulation pipes if water cooled chiller air conditioning systems are relied on (Central Air Conditioning), bulky compressors and heat pumps. But in case of this bionic inspired system alongside heat accumulation system, the designer will need to channel ducts to exhaust hot air and supply cool air. An upside down chimney channeled duct is preferred for exhausting hot air. This is taking into consideration the thermo physical properties of hot air and also the physical phenomenon of ventilation.

Auxiliary supporting systems such as Glass Facades and Vegetation when applied for conventional air conditioning systems will produce meager effects on the energy efficiency. Whereas in case of bionic inspired systems, the entire energy efficiency relies on such very small vicissitudes. Hence addition of such supporting systems will definitely prove enhancing the energy efficiency thereby reducing HVAC energy consumption.

Emissions play an important role in evaluating any component system. It is found in conventional air-conditioning systems that filters are the major source of pollution and Humidifiers are the major source of odor emissions [10] from any air-conditioning system for building. These bionic inspired systems will definitely eliminate such emissions and hence will eliminate the necessity for huge emission control systems. Apart from pollutants, carbon emissions are found to be increasingly dominant in conventional air conditioners. Carbon is a major contributor to global warming and its effects and insulates the surface of planet earth [11]. The average temperature rise of the earth is 1^0C [11]. Such bionic inspired technologies would eliminate carbon emissions too. Hence in substantial aspects, this bionic inspired air-conditioned building proves beneficial to conventional air conditioned buildings. Hence proper use of this bio mimicry will definitely prove energy efficient for buildings.

methods to improve the air quality include Control at Source, Diluting Contaminants in air using Ventilation. Certain auxiliary methods

4.0 Penguin Foot Inspired Airconditioning

The blood flow in a penguins' body serves as a source of inspiration for many thermal engineers. Penguins that live in the Antarctic Continent experience very cold temperature upto -50^0C. Despite very cold temperatures, they protect their body from frostbite. The phenomenon behind this activity is with the blood flow in the body. The blood flow for a penguin's feet is shown in Fig.7

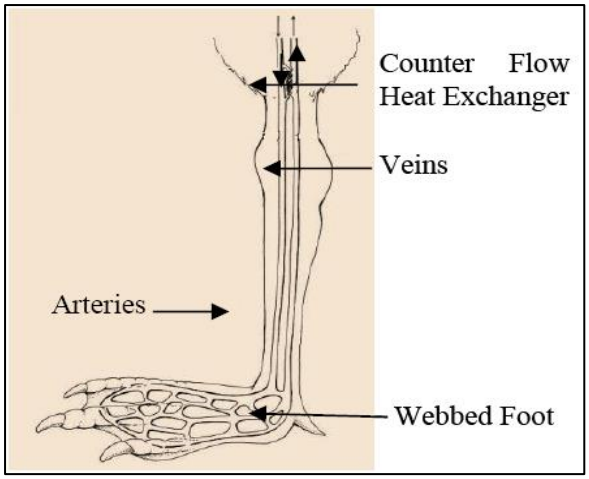
Fig 6: A Typical Penguin's Feet

In a typical penguin's foot, arteries that carry oxygenated blood from the heart and the veins that

carry deoxygenated blood to the heart have a counter current arrangement. The veins that are in contact with the webbed foot that is in direct contact with the ice have cold blood circulation, and this cold blood circulation gets heated by the arteries carrying warm blood and hence the cold blood in the veins will get warm before reaching the heart of the penguin.

4.1 Countercurrent heat exchange in penguins

Fig 7: Blood Flow in a Penguin's Foot

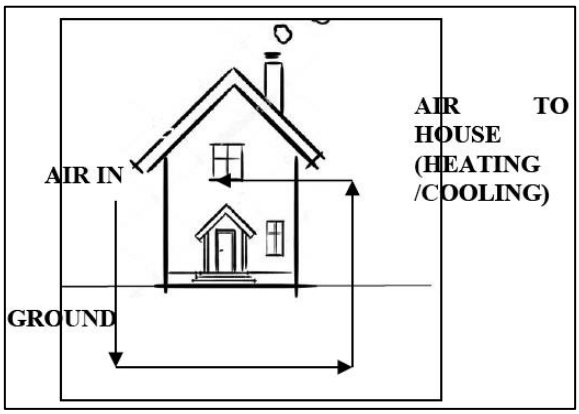


Due to this heat exchange phenomenon the interior core body of the penguin remains warmer. This blood circulation continues on protecting the penguin from getting frostbite. This phenomenon of heat exchange serves as a source of inspiration for many man-made heat exchangers.

4.2 Biomimicry of penguins for air conditioning

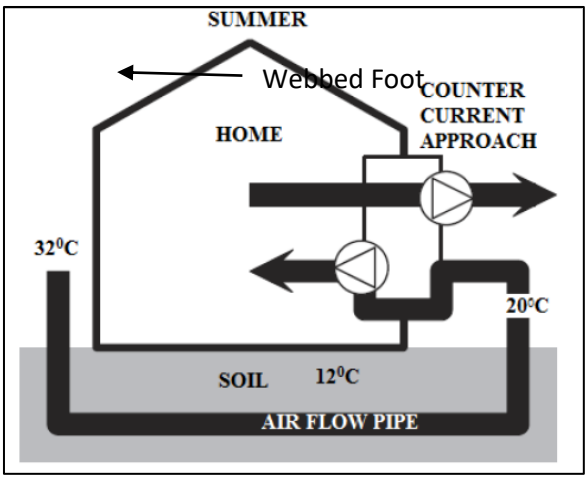
It would be highly beneficial when such counter current approach is applied to HVAC units. In the scenario of ground heat exchanger for HVAC System when integrated with counter current approach will definitely prove to enhance the efficiency on the bionic approach. A typical ground heat exchanger for HVAC Systems is as shown in Fig. 8

Fig 8: Simple Configuration of Ground Heat Exchangers for HVAC



Pierre et al [12] has tested such systems and has obtained the positive results experimentally. The system is show in Fig. 9 shows the applicability of bionic inspired counter current heat exchanger approach.

Fig 9: Experimental Configuration by Pierre et al [12]



A Computational Fluid Dynamics (CFD) Approach has been attempted to visualize such systems for Coimbatore region. The soil properties of Coimbatore region were studied. ANSYS-FLUENT Simulation Tool was used to make the analysis. The following conditions were applied to the analysis:

Table 1: Applied Conditions For CFD Analysis

Pipe Diameter (Air Flow)	0.10m
Depth of pipe insertion	2m
Temperature of soil at the depth	18
Temperature of air inlet	35^0C
Air flow Velocity	1 m/s to 10 m/s
Length of pipe (running inside	20m

soil)	
Total Length of pipe (Entry to Exit)	28m
Thermal Conductivity of Soil	1.8 W/m K
Heat Capacity of Soil	2 MJ/ m^3 K

The results from CFD Simulation have been graphically plotted as shown in Fig. 10 and Fig.11. From Fig.12, it is inferred that optimum air flow velocity is 4m/s. Fig.12 shows that at 4m/s the maximum temperature that can be achieved for the air conditioner inlet is 26^0C. This ground heat exchanger is capable of producing a 9^0C difference in temperature just by passing air flow pipes into the soil. This process is hence highly economical and energy efficient too. On the other hand, the air from inside is constantly vented to atmosphere. The counter flow approach inspired from Penguin's blood flow will function for the following benefits:

1.

s the control of soil temperature is impossible, it is possible to preheat the incoming air in a counter flow configuration to maintain a region of thermal comfort.

2.

oupling ground heat exchanger with counter flow venting exchanger will be a source for energy efficiency as it avoids bulky rotating machinery.

Fig 11: Variation in Convective Heat Transfer Coefficient

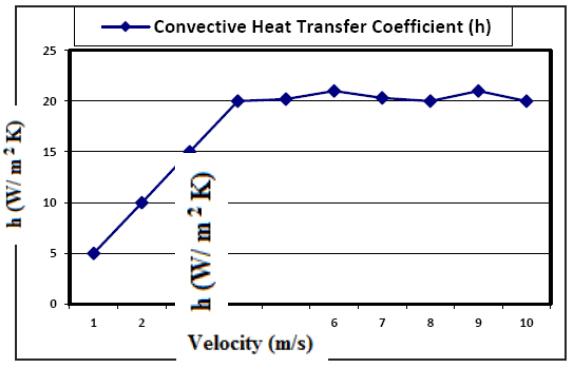
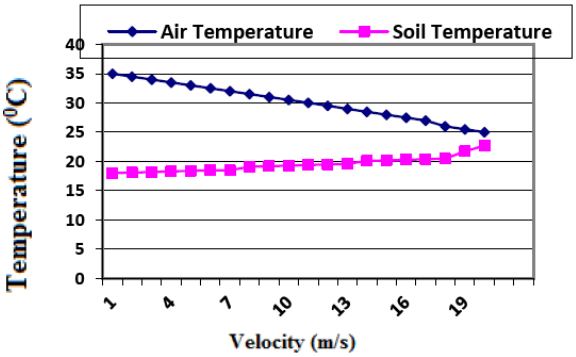


Fig 12: Variation in Temperature at 4m/s



Hence it can be inferred that Bionic inspired technology based on Penguin's counter flow approach based on blood flow proves beneficial and energy efficient.

5.0 Dehumidification in Airconditioners on Inspiration from Brown Dog Tick

A

Brown dog tick *(Rhipicephalus sanguineus)* is an insect that has attracted researchers through its weird behavior. This insect is capable to surviving several days without drinking water. The reason behind this activity has empowered researchers to

C apply the technique to air conditioning systems.

Fig 13: A Typical Brown Dog Tick

5.1 The hydrophilic analogy

The ability of the tick to absorb water vapor from the atmosphere accredits it to survive for many days, without drinking water. The tick first observes and detects a zone of high atmospheric humidity. After the detection process the tick secretes a

hydrophilic substance from its mouth. This hydrophilic secretion absorbs water vapor and the hydrated solution is then withdrawn inside the mouth of the tick.

Thus the tick rehydrates itself without directly getting to drink water. There is an analogy between this phenomenon and an activity of air conditioner.

5.2 Conventional dehumification process

Conventional vapour compression airconditioning system rely on dehumidification by cooling and condensation [14]. When fresh air that is sucked into the air conditioner is cooled beyond its Dew Point Temperature, it will condense and finally the moisture in the air comes out as water droplets. Lower the temperature of the cooling coil, drier will be the air. Achieving the Dew Point Temperature in this case is an important parameter to be considered in this activity. The process occurring in a conventional airconditioner is as show in Fig.13

Fig 13: Scheme in Conventional Air Conditioners

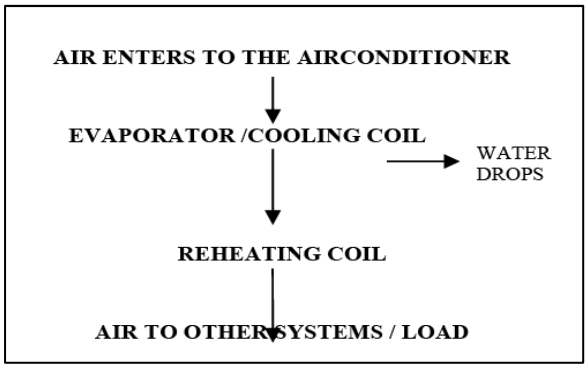
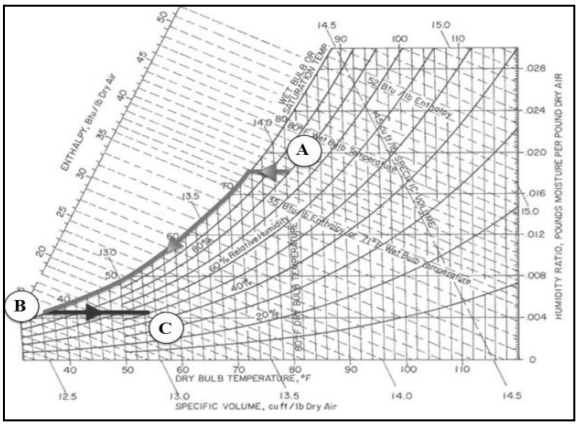


Fig.14 Conventional Cooling and Dehumidification Process in Psychrometric Chart



From Figure.14, it can be noted that:

Despite the air conditioner's primary function is to cool the air to the desired temperature output, the air conditioner will also dehumidify the air. Dehumidification has to be done to set the right humidity levels to the output air.

- **Process A – B:** Cooling and Dehumidification.
- **Process: B-C:** Reheating Process

5.3 Inspiration from the tick's activity

From the tick's activity one would find that using chemicals that would absorb moisture from air would definitely be energy efficient in a long term process. But the challenge in using such solutions lies in the saturation point of that chemical being used, hence the design must also incorporate so as to generate and regenerate the hydration process. Also the interaction of such chemical used to remove moisture with the environment must also be noted. And above all the life of such systems must be noted. Such chemical integrated systems are termed as desiccant based system. In such systems two main phases [13] are to be undertaken in the activity.

1. Desiccant Dehumidification Process
2. Regeneration of the Desiccant
3. Such desiccants systems can be classified [13] into two categories:

1. Solid Desiccant Dehumidification
2. Liquid Desiccant Dehumidification

Several configurations are being developed to incorporate such desiccants to the airconditioning unit. Some notable configurations include:

1. Rotary desiccant Dehumidifiers [14]
2. Heat Pump Driven Desiccant Dehumidifiers[14]
3. Falling liquid desiccant film on finned-tubes [15]
4. Membrane based dehumidification[16]
5. Circulating inclined fluidized beds with application for desiccant dehumidification systems [17]
6. Renewable Energy Systems integrated Desiccant Dehumidification systems [18]

Some suitable desiccants that could be used to enhance this bionic based activity are as:

1. Lithium Chloride [19]
2. Lithium Bromide [19]
3. Calcium Chloride [19]
4. Activated Carbon and Methanol [20]
5. Graphene Oxide Membranes [21]

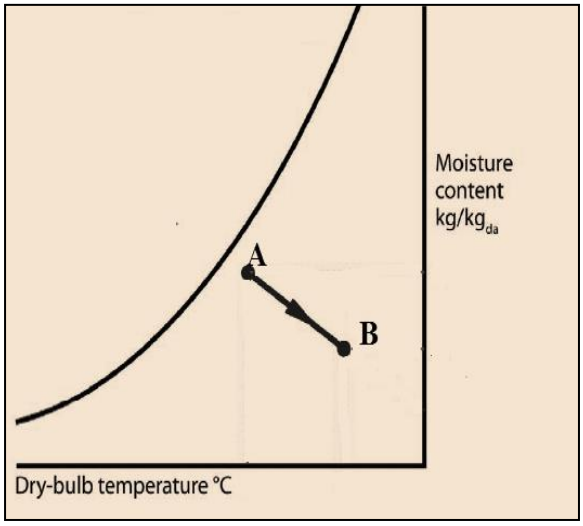
6. Modified and Unmodified Silica [22]
7. Metal Oxide [22]

In Fig.15, Process A – B indicates the desiccant based dehumification process. When compared with Fig.14, it can be noted that the dessicant dehumidification process is comparatively better compared with conventional methods of dehumdification(cooling and condensation).

5.4 Applicability of this bionic inspired system

This bionic inspired system is best fitted to a system where the air is cold, atleast below 8^0C and is humid. This system will also hold good when very low Dew Point Temperatures are required [13].

Fig 15: Desiccant Based Dehumidification



Whenever any renewable energy source is available, this bionic inspired desiccant cooling system is preferred as it would further reduce the energy requirement in regeneration of desiccants. This desiccant based system will be best suited for buildings that have a cold storage unit to store food grains, dairy products, vegetables where the humidity control will be an important criterion.

Hence, such bionic inspired air-conditioning system would definitely prove beneficial. Elimination of a few processes in conventional air conditioning will definitely make this Insect Brown Dog Tick inspired system energy efficient and would improve the quality of the process.

6.0 Conclusions

Nature has provided with multitudinous resources not just to ponder with, but also to learn from her. In this article, three inspirations from nature have been discussed. This work is just an exemplification of nature's contribution to improve technological processes.

When any technology is made to operate taking a tip from nature, would definitely satisfy the needs of any engineer; energy efficiency, economy and reliability.

It is upto the technically termed *'homo sapiens'* to use Nature in a fruitful way paving ways ahead for the forthcoming generations.

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