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Alternative Air-Conditioning Options for Developing Countries

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***Abstract*—This study assesses the potential selection of efficient air-conditioning (AC) and cooling systems in order to avoid excess power consumption, mitigation of harmful refrigerants generated by the existing AC systems. Several varieties of active and passive air-conditioning systems i.e. heating ventilating air-conditioning (HVAC), vapor compression air-conditioning (VCAC) conventional direct evaporative cooling (DEC) and indirect evaporative cooling (IEC) and desiccant air-conditioning (DAC) systems are under practice for the cooling and dehumidification. The storage of agricultural products mainly based on product individual characteristics i.e. respiration rate, transpiration rate and moisture content of that product. Variant ambient air conditions and the type of application are the main parameters for the choice of air-conditioning system to get optimum performance. The DAC system subsidize the coefficient of performance (COP) in humid regions, coastal ranges of developing countries e.g. Karachi and Gawadar (Pakistan) with hot humid climatic conditions. In similar way, hottest regions of the country such as Sibbi, Jacobabad and Multan perform better results when incorporates with M-cycle evaporative cooling system. Variation in ambient air conditions directly affect the cooling load and the choice of sustainable air-conditioning system.**

***Index Terms*—Evaporative Cooling; Air-Conditioning; Alternative Options.**

I. Introduction

Storage and preservation of food materials for lateral use has been a great task for mankind throughout the human history. Maintaining quality, quantity and minimizing the deterioration of food products from harvest to table use (shelf life) are the basic requirements of product storage. Different techniques have been adopted for this purposes i.e. drying, chemical treatment, ionization, mechanical isolation and refrigeration etc. No doubt these techniques have proven good at some extent but have limitations under different circumstances. Storage mainly depend upon the specific characteristics of the individual products i.e. respiration rate, transpiration, moisture content and water activity, and also depend upon on humidity and temperature of the surrounding environment. These features demands a separate control environment for distinct product storage.

It is well known that hot environment lowers the productive and reproductive efficiency of farmhouse wildlife [1]. The provision of thermal comfort zone is necessary to get the maximum production from farmhouse animals including milk and meat. Furthermore, as multi climate country requires variety of air-conditioning system in order to reach the optimum performance. Agricultural product storage systems are limited to the ice and refrigeration in big marketplaces whereas animal air-conditioning has not been yet practiced in most of developing countries.

Air-conditioning (AC) is a technique in which temperature and humidity of air in specified environment is simultaneously control in order to change the indoor air condition [2]. Several types of AC systems such as heating ventilating air-conditioning (HVAC),vapor compression air-conditioning (VCAC), direct evaporative cooling (DEC), indirect evaporative cooling (IEC) and desiccant air-conditioning (DAC) are the under operation for the cooling of residential areas, commercial buildings school, offices for thermal comfort and for agri-product storage. The commonly used air-conditioning system for human thermal comfort is mechanical vapor compression system [3].

VCAC technology although give better results to achieve the require temperature but used harmful refrigerants and consume excess amount of energy [4]. Among all these systems the DEC, IEC and DAC are low-cost, energy efficient and environmental friendly techniques. These techniques have not been practiced for the storage of agri-products. In this technique a favorable environment is created for each product according to its characteristics and regional climate parameters.

A recent innovation in evaporative cooling field has come by a thermodynamic process named Maisotsenko cycle (M-Cycle) that produce cooling by latent heat of evaporation of water into the air, by reaching the ambient air temperature to the dew-point below the wet bulb temperature.

II. Air-Conditioning System

AC is a process that simultaneously control the temperature and humidity of air in a control environment. Multi climate region that demands different types of air-conditioning and cooling systems for hot, dry and humid climate in order to optimized energy consumption. Air-conditioning load calculations can be made on the base of average climatic conditions of the individual cities [5]. This portion covers the discussion of various AC systems that are low cost, energy efficient and environmentally acceptable i.e. evaporative cooling, Desiccant air-conditioning and Maisotsenko cycle air-conditioning systems. These systems may be active or passive used for the cooling of existing and newly constructing buildings.

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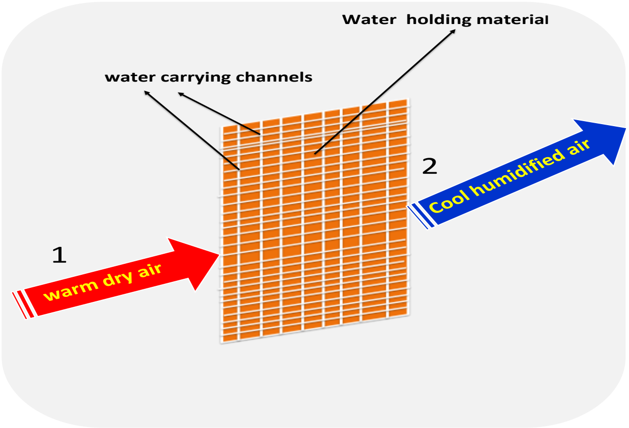

Fig. 1. Schematic of DEC.

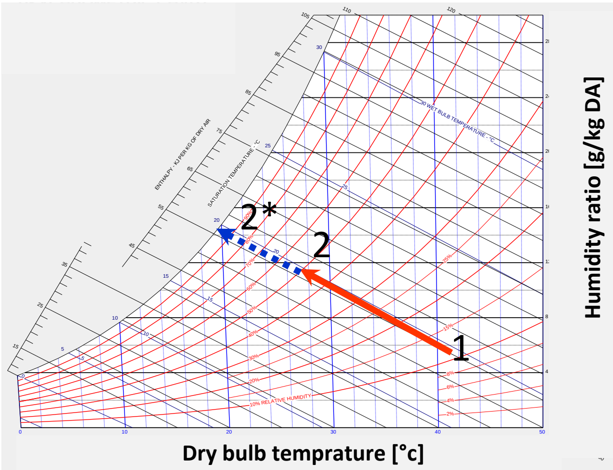

Fig. 2. Psychrometric Representation of DEC.

A. *Conventional Evaporating cooling*

Evaporative cooling is an environmental friendly and energy efficient system that meets the cooling requirements of buildings in hot and dry climate. Evaporative cooling commonly used two principals DEC and IEC.

1) *Direct Evaporative Cooling (DEC)*

DEC is the simplest and widely used system in air-conditioning system. In DEC the temperature of ambient air goes to wet bulb condition by direct contacting of air with evaporating water. This system typically consists of fan that draw hot ambient air and pass it through wetted porous medium that is capable of holding some water. The porous medium may be jute, fibers, cellulose papers and spray of water [6]. Water absorb heat for its evaporation through the air flow passing through the porous medium and air. Direct evaporative cooling system can be used as a humidifier in arid regions as well can reduce the air temperature [7]. DEC gives the better coefficient in arid regions where ambient air is less humid [8]. DEC system has about 70–95% effectiveness in terms of temperature depression [9]. In Fig. 1, process of DEC is shown in which hot ambient air 1 enter the wetted porous medium through one side and become cool and humidified air 2 due to latent heat of water evaporation. Water enter from the upper side of porous medium in order to wet it, and evaporate by absorbing the heat from ambient air during downward movement. Psychrometric representation of DEC is shown in Fig. 2.

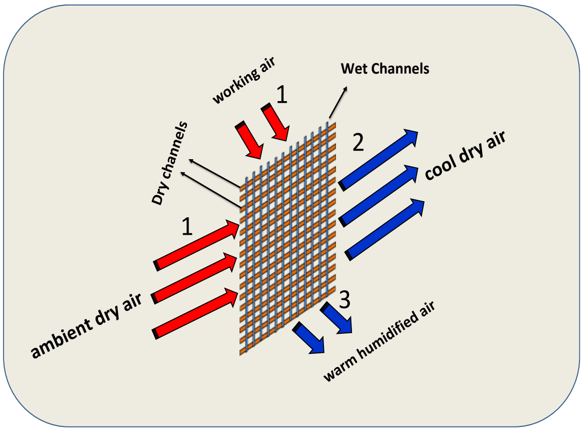

Fig. 3. Schematic of IEC.

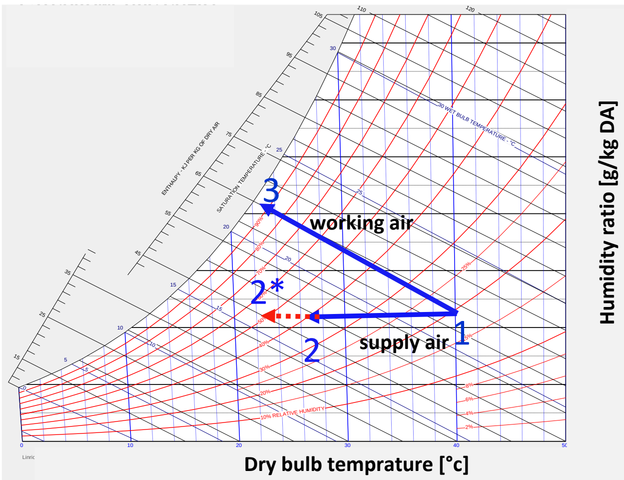

Fig. 4. Psychrometric Representation of IEC.

2) *Indirect Evaporative Cooling (IEC)*

In this system ambient hot air is cooled without humidification and cool down the ambient air temperature to wet-bulb temperature and its wet bulb effectiveness ranges 0.55-9.65. It consists two parts wet passages for the flow of water and dry passages for the flow of air. These passages are connected mechanically each other by a layer that is permeable to heat transfer between wet and dry passages.

Water is evaporated through wet passages and cause the cool down of ambient air passing through dry passages. In Fig. 3, the water move from to top to downward in the wet passages and air move Crosswise through dry passages and at the end of dry side, air temperature is low than ambient air temperature. The Psychrometric representation of IEC is given in Fig. 4.

B. *Maisotsenko Cycle Evaporating Cooling (MEC)*

A thermodynamic practice that achieves energy from the evaporating of water into air by latent heat is known Maisotsenko cycle (M-cycle) [10]. Referring to Fig. 5, basically it is a combine process of heat transfer and evaporating cooling to enable temperature to extent the dew-point temperature of ambient air. In other words, it is the advance development of indirect evaporating cooling (IEC) through which air can be cool to dew-point temperature instead of wet-bulb temperature M-cycle air-conditioning provide hot humid air for winter season and dew-point cool air for summer season.

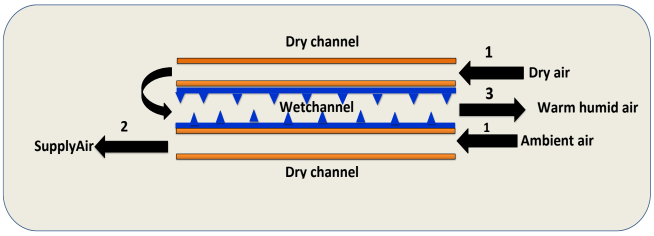

Fig. 5. Schematic of MEC.

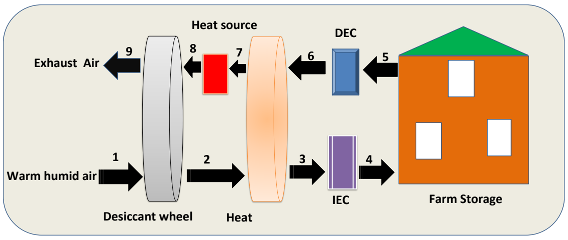

Fig. 7. Schematic of DAC.

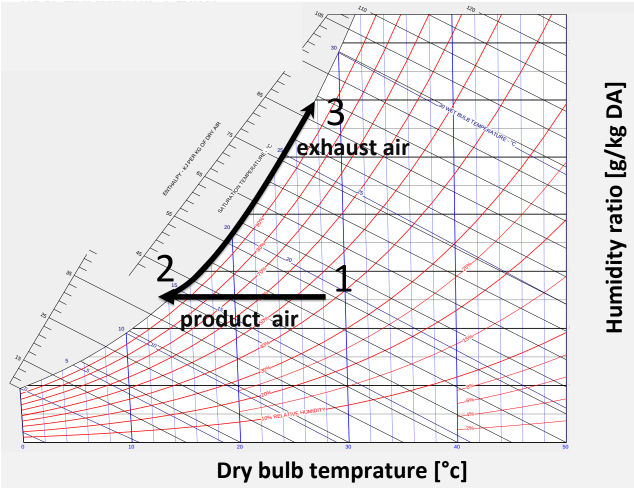

Fig. 6. Psychrometric representation of MEC.

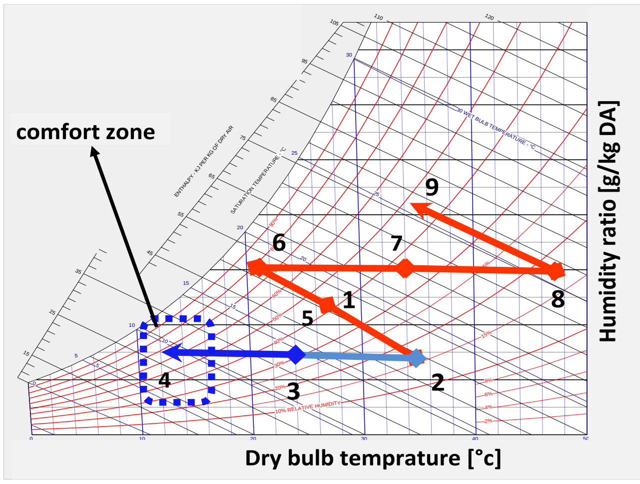

Fig. 8. Psychrometric representation of DAC.

M-cycle typically consists of two channels for DEC system and three channels for IEC system [10]. In above schematic it consists thee channels two are dry channels above and below and one is wet channel that sandwich between two dry channels. Ambient air enter in the dry channel and become cool due to convection heat transfer from dry channel to wet channel process 1-2, and then pass through wet channel in which water is spraying in order insure the maximum evaporation and air gets warm and humid process 2-3 by absorbing the heat. Ambient air goes through below dry channel gets cool dry air use as conditioned supply air. Its psychrometric representation is given in Fig. 6.

C. Desiccant Air-Conditioning system (DAC)

A desiccant air-conditioning (DAC) system consists of dehumidification unit to control the humidity of the process air, coupled with AC system. Dehumidification unit incorporates an absorbent or adsorbent like silica gel that hygroscopic in nature to absorb moisture due to vapor pressure difference between surrounding air and desiccant material. DAC is getting importance on both sides on commercial level as well as at agriculture sector for its intensive applicability. The working principle of DAC is given in Fig. 7 by its schematic diagram and in Fig. 8 by its psychrometric diagram.

The outdoor air pass through desiccant wheel process 1-2 become dehumidified and this dehumidified air then cool at constant humidity ratio through heat exchanger process 2-3. This processed air is additionally cool by cooling unit either DEC or IEC process 3-4 and then deliver to the conditioning zone. The return air from the conditioned zone is again used for heat recovery processes on the regeneration side. The return air is pass through heat exchanger process 6-7 become warm as to recover the heat, additionally heated through heat source process 7-8 and then pass through desiccant wheel process 8-9, become hot and humid as an exhaust air.

III. Results And Discussion

Various kinds of AC systems such as conventional VCAC, HVAC, DEC, IEC, MAC and Desiccant are being under practice for the air-conditioning of buildings at domestic level as well as at commercial level. Low-cost, energy efficient with no greenhouse emission are the parameters that give the optimum performance of either system.

The comparison among the conventional VCAC cycle, DEC cycle, IEC cycle, desiccant cycle and MAC cycle have been studied in on the psychrometric chart as shown in Fig. 9 [11]. The comparison shows that conventional VCAC cycle consume excess input energy and operate with some hazardous refrigerants that responsible for global warming whereas DEC cycle and IEC cycle are natural base that cause the cooling due to evaporation of water with low input cost. Desiccant dehumidification unit subsidize the performance of DEC or IEC systems for its better applications in humid climate. M-Cycle evaporative cooling systems offers warm humid air in winter and cool dry air in summer simultaneously by receiving the energy from latent heat through evaporation of water into the air. Depending upon the different standards the evaporating cooling systems give better coefficient of performance for farm air conditioning over conventional VCAC or HVAC systems.

It is well known that hot environments lowers productive and reproductive efficiency in farmhouse wildlife [1]. To get the maximum production from farmhouse animals including milk and meat, it is necessary to provide them thermal comfort zone. Air-conditioning systems are being under

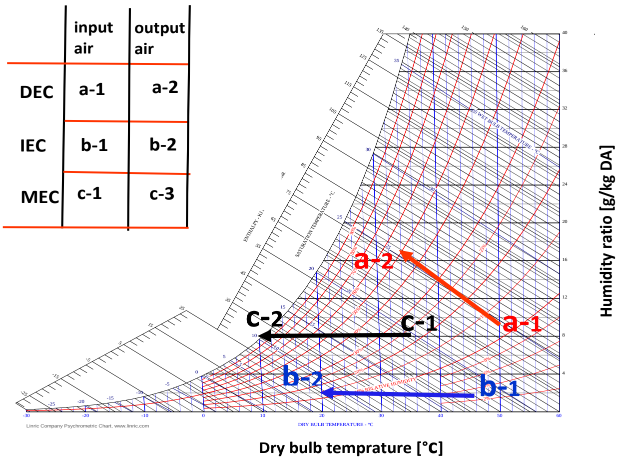

Fig. 9. Psychrometric comparison of DEC, IEC and MAC systems.

practice to generate favorable environment for animal thermal comfort as well as for the preservation and storage of agricultural products. The selection of air-conditioning system for each animal category varies as each animal has differ respiration and heat generating rate. An AC system with specified temperature and humidity control can't provide the thermal comfort zones for all categories of the animals. Thermal comfort zones for each category of animal with varying ranges of temperature and humidity are shown on Psychrometric chart [12]. These Psychrometric comfort zones offer design parameters of air-conditioning system for individual group of animals.

In same manners, each agricultural product, fruits and vegetables demands separate air-conditioning system depending on the individual product characteristics including water activity, respiration and transpiration rate. The measures of these parameters will help in generating the required temperature and humidity of that individual product. Psychrometric representation of preservation and storage zones for fruits and vegetables [12] shows various comfort product storage zones for various agricultural products on the Psychrometric chart. Green tomatoes requires temperature ranges 18 - 22 C° whereas grapes can be store comfortably in (-10 – 0 C°) with nearly same humidity.

IV. Conclusion

Study concluded that DEC, IEC, M-Cycle, and DAC can collectively provide ideal conditions of temperature and humidity for farm air-conditioning including for animal air-conditioning or for the storage of fruits and vegetables. Due to the variant ambient air conditions one or the other could produce the optimum choice for sustainable air-conditioning system. This study suggest the future work for of dynamic simulation for each and every application at domestic as well as at commercial level.

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