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Investigation of Desiccant and Evaporative Cooling Systems for Animal Air-Conditioning

Muhammad Sultan, Hassan Niaz and Takahiko Miyazaki

Abstract

Productivity of livestock animals particularly sheep, goats, dairy, and beef cattle are usually affected due to high thermal/heat (sensible and latent) stresses, particularly in the developing countries. Different types of heating, ventilation, and air-conditioning (HVAC) systems are used worldwide depending upon the ambient air conditions to achieve the animals' thermal comfort. In this chapter, few low-cost options for the air-conditioning system and for farm building designs are discussed. Desiccant-based two air-conditioning systems are considered i.e., standalone desiccant air-conditioning (D-AC) and M-cycle assisted D-AC (M-DAC) system. The feasibility of both systems is thermodynamically checked for climatic conditions of Multan, Pakistan. Daily- basis data of ambient and processed air from both systems are analyzed for the thermal comfort of Holstein Friesian cows. Temperature humidity index (THI) is calculated to investigate the thermal heat stress conditions. Results showed that the D-AC system can be used efficiently in the humid climatic conditions with relatively moderate-to-low temperatures. On the other hand, the M-DAC system can be used in humid climatic conditions with relatively high-temperature conditions. It is important to mention that the typical direct evaporative cooling systems can be obviously low-cost options in case of dry climatic conditions.

Keywords: desiccant, evaporative cooling, air-conditioning, animal, M-cycle, thermal comfort

1. Introduction

Air-conditioning (AC) is a basic need for thermal comfort of humans as well as for animals. Living space per capita in case of human is decreasing due to population increase; therefore, it is difficult to provide huge space to animals with high natural ventilation. Thus, compact size farms with good thermal comfort conditions are needed. For this purpose, many air-conditioning systems are being used globally. The conventional AC systems use almost half of the total energy which is a huge amount of primary energy. So, energy efficient AC systems are principally required for animals particularly for developing countries. In case of Pakistan, animals contribute about 70–75% of the total agricultural GDP share [1] which is huge number. Livestock is sometime neglected area of research in developing

countries e.g., Pakistan, Bangladesh, India, African countries etc. Therefore, the benefit from the livestock sector of such countries can be significantly increased by providing low-cost sustainable farm technologies [2]. Animals' thermal comfort includes the mechanisms of metabolism rate, skin heat transfer, rate of respiration, genetic factor and nature of feed, etc., [3–5]. That's why, it is important to air condition the space for animals to enhance the output products e.g., milk, fertility, meat and other related products etc., [2, 4, 6].

Figure 1 shows the illustration of the different heat transfer phenomena between environment and animals and the psychrometric thermal comfort zones for different animal species [7]. Most commonly heat transfer phenomena are considered which govern the fundamental equations for load calculations. Similarly, comfort zones elaborate the limit of temperature and relative humidity required for the ideal growth of different species [5, 8].

This chapter focuses on ideal heat transfer and comfort zones for the different species of animals. A set of equations is used for the measurement of the heat load
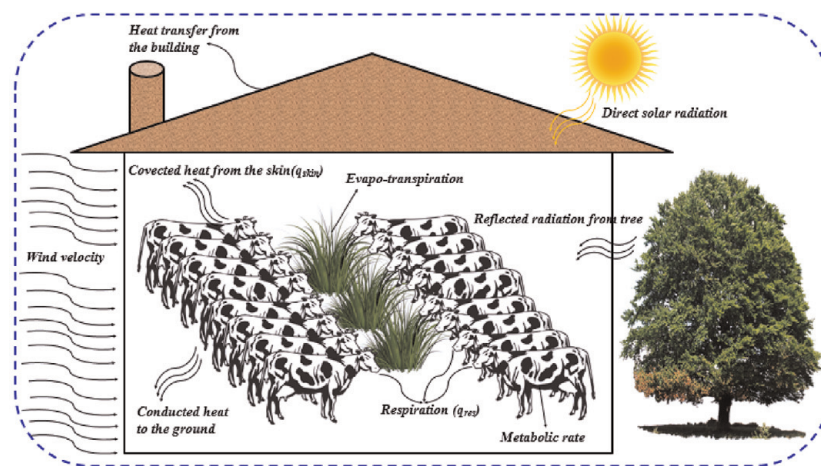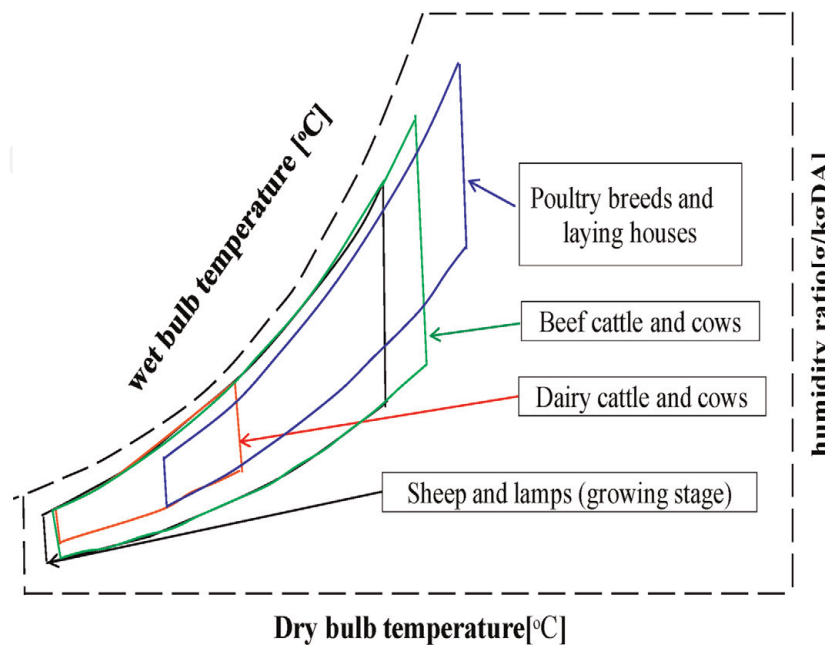
Figure 1.
Simplified illustration of: (A) animals heat transfer phenomena, and (B) psychrometric thermal comfort zones for different animals.

calculation for farm animals (Holstein Friesian Cow and Poultry application). Evaporative cooling and desiccant based air-conditioning systems are discussed according to the thermal comfort requirements for the animals. Jurinak model [9–13] is used for the evaluation of desiccant block and simplified correlations are used for performance evaluation of heat exchanger [14] and M-cycle cooling system [5]. Building designs and associated key factors affecting are also discussed for the subjected application. Moreover, the feasibility of systems is checked for the climatic conditions of Multan, Pakistan. Some other authors [15–18] also evaluate for animal applications the different AC systems (desiccant based and evaporative cooling-based systems) for different ventilation arrangements.

The novelty of this book chapter is to introduce the methods to calculate the heat load calculations for Holstein Friesian cows and poultry applications for the climatic conditions of Multan, Pakistan. The AC systems (standalone and combined) proposed for animal air-conditioning are not used for discussed applications before for the climatic conditions of Multan, Pakistan.

## 2. Ventilation rate and building designs for animal housings

2.1 Significance of ventilation rate

Ventilation is one of the important techniques used to control the thermal stresses in case of animals. Lots of studies have showed the significance of ventilation rate for achieving the ideal thermal comfort, and thereby, ventilation rate is considered an essential parameter for animal air-conditioning [5, 15, 16–19]. For example, **Figure 2** shows the factors affecting the selection of ventilation rate [20]. The suffocation or level of O_2/CO_2 is usually controlled by the air flow rate which must be designed precisely depending upon the nature of application. For livestock applications, ventilation is highly required to avoid the heat stress condition especially dairy cattle [17–20]. Dairy products, meat production, and other livestock applications need enough oxygen for longer storage period especially at commercial level. The ventilation rate depends upon the nature of the application and the climatic condition of the area for which the AC is needed [5, 21, 22]. It is considered the key parameter to measure and to create the thermal comfort.

### 2.2 Climate control and farm building designs

Advanced animals' AC options are limited in developing countries due to high initial and maintenance cost. Small farmers/stake holders cannot afford much cost. In addition, building designs are not very efficient in terms of providing thermal comfort to the farm animals [5, 7, 23]. In many developing countries including Pakistan, open side walls covered with sieve like material (natural ventilation) are used for cross flow of air with a flat roof [24]. Natural ventilation is good in maintaining the temperature, humidity and suffocation in cattle barns especially [23]. Instead, mechanical ventilation (active or passive) avoids the excess amount of carbon dioxide and ammonia in the air which can cause diseases and growth rate declination. Furthermore, the building designs can be further modified with respect to ventilation requirements and thermal comfort requirements [5, 7, 8, 23]. In this regard, researchers use different types of ventilation orientations [3, 5, 23, 25].

First type of ventilation is base ventilation as shown in **Figure 3a**. Negative pressure is created by lateral fans inside the house ejecting the exhaust air outside (brown arrows). Supply clean air (green arrows) is entered through the windows on the opposite wall that creates ventilation flow in the cross direction that guarantees
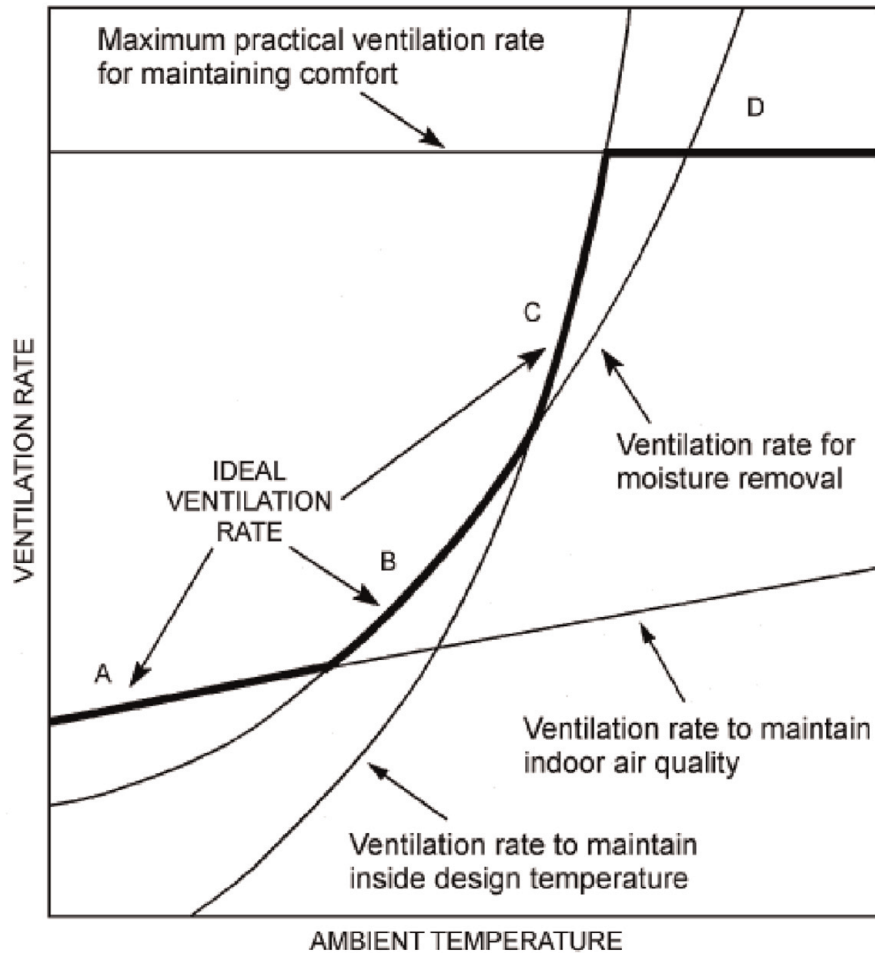
Figure 2.
*Selection of ventilation rate for livestock application [20].*

indoor air quality control. Base ventilation in rectangular shaped farm sheds which are used with fans at one end and the holes at roof and opposite side of the building which allows the cross flow of the air. Base flow is normally used to control indoor air quality for the circulation of the air which reduces the contaminants of harmful gases in the air [3, 25]. The second type of the ventilation is tunnel ventilation as shown in **Figure 3b**. This is due to the horizontal movement of air in the farm shed. There are greater number of fans used than that of base ventilation. It can be seen that the hot air is ejected through the fans placed at the end of the house outside (red arrows), that creates a negative pressure inside the building. Due to the pressure difference, fresh outdoor air is entered (blue arrows) through the inlets decreasing the indoor air temperature. In this type of ventilation, air temperature is decreased due to the removal of thermal emission of the animals and wind-chill effect is produced [3, 7, 14, 26]. Air speed does not exceed 3 ms^{-1} in this type of ventilation, otherwise thermal discomfort occurs. When tunnel ventilation is not enough to provide thermal comfort in the farm sheds, evaporative cooling systems are additionally used. The evaporative cooling (EC) shown in the **Figure 3c** converts sensible heat into latent which is carried out by evaporative pads. It can be seen that the negative pressure is created inside the house by the fans which lets the hot external air pass through the wet evaporative pads that decreases the air temperature (red/blue arrows). The indoor air temperature is decreased and is expelled by the tunnel ventilation fans (red arrows). During the warmest periods, ambient air passes through the evaporative pads where air is cooled due to evaporation of the water [3, 7, 8, 25]. This decreases the outlet air and consequently, indoor air temperature also decreases. Cooling pads are configured on the larger side of the
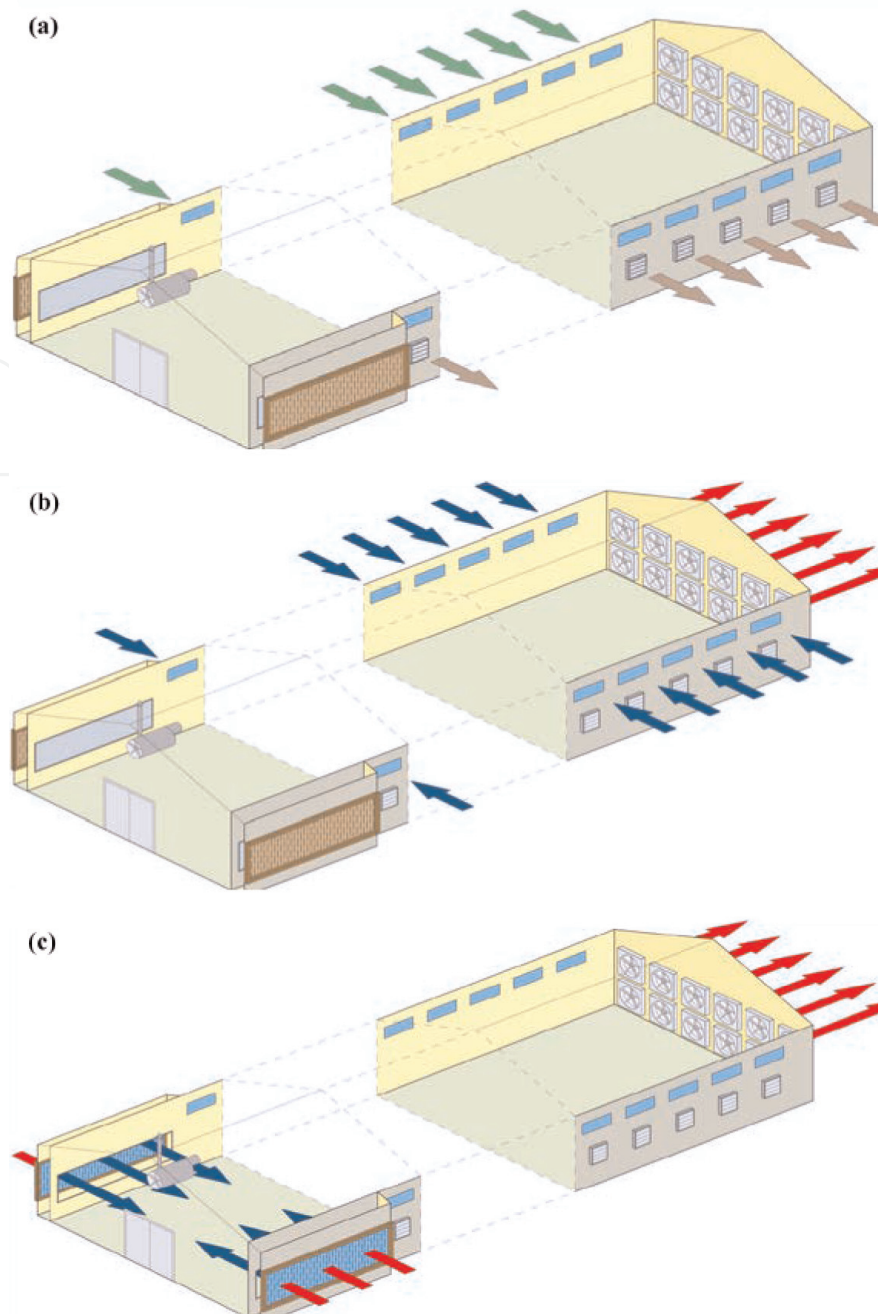
Figure 3.
Illustration of operating principle for: (a) base ventilation, (b) tunnel ventilation, and (c) evaporative cooling [3].

building wall opposite to the tunnel ventilation fans which allows the passage of cooled air due to negative pressure [3].

The side view of the evaporative pads used in the farm sheds is shown in **Figure 4a** and the schematic diagram of the evaporative cooling system as shown in the **Figure 4b**. Evaporative cooling (EC) is a system of water vapor evaporating into air that cools the air by water evaporation. In a study [7, 16], authors used honeycomb like structure for the evaporation supportive channel. In that channel, water is supplied from upside down with the help of a sprinkler. Air is passed through that honeycomb structure from one side to another side. The fan is used for the controlled flow of air in the system. There is a cylinder of water that collects water whereas a water pump is used to flow the water from the tank to the sprinkler as shown in **Figure 4b**. This can be a low-cost method to attain thermal comfort conditions in controlled sheds in hot climatic conditions except in rainy season (monsoon season).
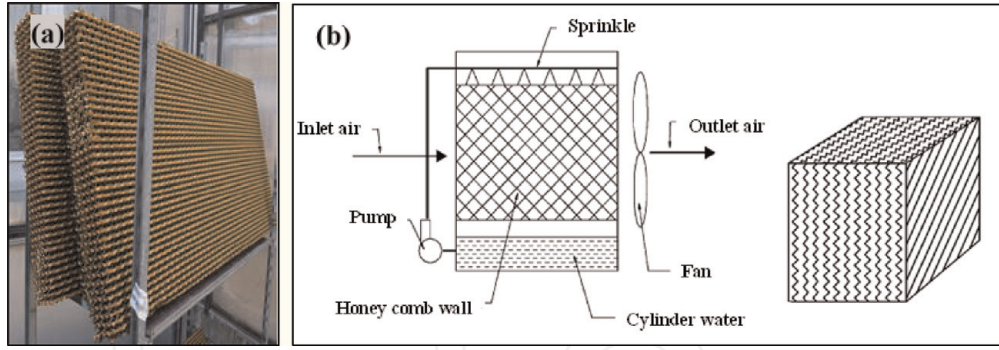
Figure 4.
A view of: (a) cellulose evaporative pads [3]; and (b) schematic diagram of evaporative cooling system [7].

3. Methodology: animals' thermal comfort

Farm animals' thermal comfort is estimated for the viewpoint of optimum productivity. Different temperature and humidity values are required for different types of animals [7]. The heat transfer between farm animals and surrounding environment is expressed in **Figure 1a**. The heat transfer phenomenon between animal and environment is associated with conduction, convection, radiation, evaporation, evapotranspiration, wind velocity and metabolism rate (sensible and latent energy/heat transfer through animal skin). Heat transfer through building is also considerable while designing the animals' farm building. Temperature humidity index (THI) is one of the key parameters to measure the environmental condition for the farm animals. The thermal threshold values for Holstein Friesian cows are 72 for thermal neutral region and above than 72 for heat stress region [6]. The total heat load is calculated by following Eqs. (1)–(9). Total amount of heat is the sum of heat load for animals and heat load for building as shown in Eq. (8). Eq. (1) is used for the calculation of total heat load for animals [14] as follows:

$$Q_a = q_{skin} + q_{res} + S \tag{1}$$

where, Q_a is total amount of heat for animals (kW), q is the partial heat load for the different sections (kW), and S is the amount of heat stored in the body (for ideal case: S = 0). The subscripts "a" and "res" denote animals and respiration, respectively. Heat load for respiration is calculated by the Eqs. (2) and (3) [14, 19] as given by:

$$q_{skin} = S_A M_R \tag{2}$$

$$S_A = 0.147 \, W^{0.57} \tag{3}$$

where, W is the weight of animal (kg), S_A is the surface area of skin (m^2), and M_R denotes the metabolism rate (met). The heat of respiration which is the sum of evaporation and convection heat loss is calculated by the Eqs. (4)–(6) [14].

$$q_{res} = C_{res} + E_{res} \tag{4}$$

$$C_{res} = [0.0014 \, M_R (34 - T_a)] \tag{5}$$

$$E_{res} = [0.0173 \, M_R (5.87 - P_a)] \tag{6}$$

where, C is the convection heat loss from respiration [W/(h.m^2)], E is the evaporation heat loss from respiration [W/(h.m^2)], and M_R is metabolic rate (met). The terms T_a and P_a represents ambient air temperature (°C) and vapor pressure

(kPa), respectively. Total amount of heat transfer through buildings is calculated by Eq. (7) as given by:

$$Q_b = U \, A \, \Delta T \tag{7}$$

where, Q_b is the total heat load for buildings (kW), U is overall heat transfer coefficient for building [W/(m².K)], A is the area of building (m²), and ΔT is the temperature difference (°C or K). Total amount of heat required for the thermal comfort of farm animals is calculated by Eq. (8) as follows:

$$Q = Q_a + Q_b \tag{8}$$

where, Q is the total amount of heat load (kW). Temperature humidity index (THI) is important parameter which is used to measure the environment condition i.e., whether the region is in heat stress condition or in thermal neutral condition. THI is calculated by the Eq. (9) [4, 6] as given below:

$$THI = (1.8 \, T + 32) - [(0.55 - 0.0055 \, RH)(1.8 \, T - 26)] \tag{9}$$

where, THI is the temperature humidity index [−], T is the temperature (°C), and RH is the relative humidity (%). As the THI is dependent on temperature and humidity, therefore, typical values of THI can also be found from the literature as given by reference [6]. A region is considered thermal neutral region when THI < 68, and the region is thermally stable region when THI = 68–72. The region is moderate heat stress region when THI = 72–80 and the region is severe heat stress region when THI > 80.

Similarly, to cows and cattle, THI is also calculated for poultry birds [23, 27]. THI equation for poultry applications is given by Eq. (10) as reported in Ref. [27]:

$$THI = 0.6T_{db} + 0.4T_{wb} \tag{10}$$

where, T is the temperature (°C). The subscripts "db" and "wb" denote dry-bulb and wet-bulb, respectively. The interior dry-bulb and wet-bulb temperatures can be calculated according to the Eqs. (11) and (12). For the air-conditioned space by evaporative cooler, interior dry-bulb temperature and humidity ratio is calculated from sensible and latent heat equations for the building as follows:

$$t_{i, \, db} = t_{o, \, db} + \frac{Q_s(\text{age}, t_{o, \, db}) n_{birds} m_{birds} - \beta \, \dot{m}_w \, h_{fg}}{\dot{m}_a c_p} \tag{11}$$

$$W_i = W_o + \frac{Q_L(\text{age}, t_{i, \, db}) m_{birds} - \beta \, \dot{m}_w \, h_{fg}}{\dot{m}_a h_{fg}} \tag{12}$$

where, t is the temperature (°C), Q is the heat production (W), n_{birds} is the number of birds, and m_{birds} is the mass per bird (kg). The term $\beta \, \dot{m}_w$ represents the mass flow rate of the moisture in the air and h_{fg} denotes latent heat of vaporization i.e., nearly 2.43 MJ kg⁻¹ at 30°C. The term C_p shows specific heat of air i.e., 1006 J kg⁻¹ K⁻¹. The subscripts "i," "o," "db," "wb," "S," "L," "a," and "w" denote inside, outside, dry-bulb, wet-bulb, sensible, latent, air, and water, respectively.

4. Proposed air-conditioning systems

There are many innovative modern AC technologies that are used globally in addition to vapor compressor-based systems. These systems mainly use the

conception of evaporative cooling adsorption cooling and desiccant AC. These systems are not explored extensively in developing countries. Direct evaporative cooling system (swamp cooler) is most common system used worldwide wherever dry climatic conditions exists. Thermal comfort and/or temperature/humidity control are becoming more popular and demanding day by day in agriculture sector particularly for product storage, post-harvest processing, farm animals' buildings, as well as transportation of dairy, meat and food products [1, 15, 28, 29]. Thermal comfort for agricultural products and livestock requires cooling (temperature control) as well as humidity control and ventilation. These requirements change with the change in application and climatic conditions from one to another. Therefore, above mentioned thermally driven AC systems can be used for this purpose [5, 7, 8, 15].

4.1 Standalone desiccant air-conditioning (D-AC) system

Standalone desiccant air-conditioning (D-AC) system consists of a desiccant unit (wheel or block) mostly with the addition of heat-exchanger (HX). There is no cooling device principally used in the D-AC system. The D-AC system is used for the humidity control. It is relatively more efficient in the humid regions where humidity control is primarily required. It may also feasible for the applications in which humidity control is mainly concerned (i.e., storage of onion and leafy vegetables) [8, 11, 15, 26].

The schematic diagram of the D-AC system is shown in **Figure 5a**. The standalone D-AC system consists of two desiccant blocks (DB-1 and DB-2) used for the dehumidification of air. The dehumidified (relatively warmer) air is passed through the HX where the temperature of the air becomes equal to the ambient air (ideally). After that, the cooled air may be used for the desired application. The total process is known as the air dehumidification cycle. However, in regeneration cycle, the desiccant unit is regenerated by passing the hot air. Therefore, a heating unit is used D-AC system to heat up the air. Then the heated air is passed through the desiccant unit to remove its moisture in order to be used for cyclic process. The heating unit usually uses thermal energy sources i.e., waste heat, biogas, biomass, direct thermal energy (from solar or likewise), geothermal energy, etc. The regeneration depends upon the material type, ambient air conditions and other factors related to the material properties. Thus, regenerations temperature may be changed with the change in these factors.

A set of equations given by Jurinak model [9–13, 30] is used for performance evaluation of the desiccant unit.
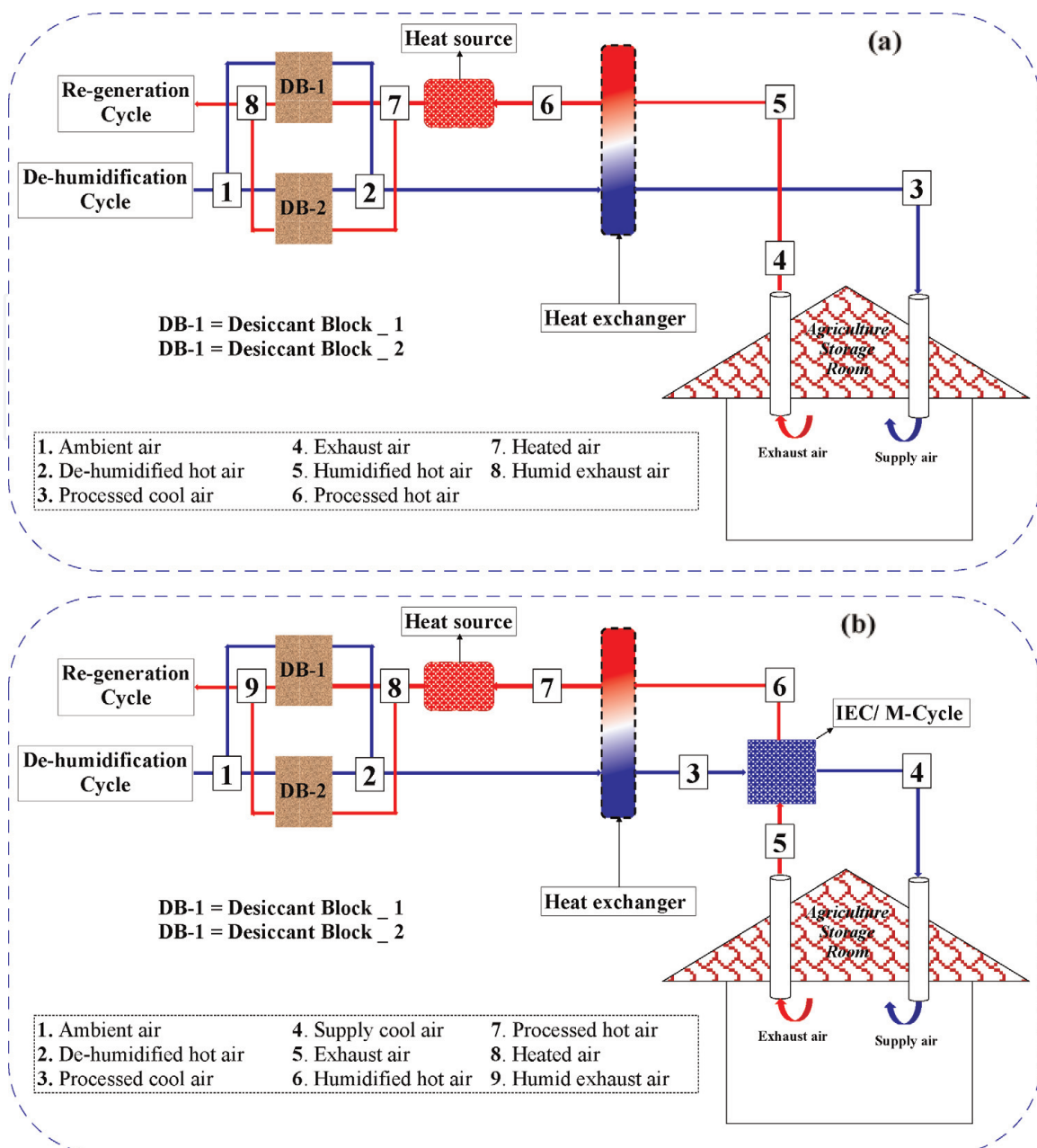
$$F_{1,\,ip} = \frac{\varphi_1}{(T_{ip} + 273.15)^{1.49}} + \tau_1 \left(\frac{w_{ip}}{1000}\right)^{\gamma_1} \tag{13}$$

$$F_{2,\,ip} = \frac{(T_{ip} + 273.15)^{1.49}}{\varphi_2} - \tau_2 \left(\frac{w_{ip}}{1000}\right)^{\gamma_2} \tag{14}$$

$$\eta_{F1} = \frac{F_{1,\,2} - F_{1,\,1}}{F_{1,\,8} - F_{1,\,1}} \tag{15}$$

$$\eta_{F2} = \frac{F_{2,\,2} - F_{2,\,1}}{F_{2,\,8} - F_{2,\,1}} \tag{16}$$

where, F_1 and F_2 are combined potentials [−], and η_{F1}, η_{F2} are the efficiencies of the combined potentials. The term "*ip*" indicates the state of air in the system (1, 2, and 8). Eqs. (13)–(16) are used for the performance evaluation of the

Figure 5.
Schematic diagram for: (a) standalone desiccant AC (D-AC) system and (b) M-cycle assisted desiccant AC (M-DAC) system.

desiccant unit with the help of MS excel solver. The typical values for the efficiencies are taken as: $(\eta_{F1}, \eta_{F2}) = (0.05, 0.95)$ for the high performance of desiccant unit as reported by [8–13]. The values for the constants are given in **Table 1**.

The performance of the desiccant unit was evaluated by given equations and also can be validated for the different climatic conditions (especially for developing countries). The processed air through the desiccant unit has higher temperature and low relative humidity as comparison with the ambient air conditions. The hot air passes through the heat exchanger where the temperature of the air decreases, but the humidity ratio remains constant. The temperature of the air is calculated by Eq. (17) [14].

$$T_3 = T_{2,db} - \varepsilon_{HX}\left(T_{2,db} - T_{1,db}\right) \tag{17}$$

where, "ε" is the efficiency of the HX whose value is taken as 0.90. The T_3 is the air temperature (°C) which has to be calculated. The T_2 is the temperature (°C) of

Parameter	Value	Parameter	Value
φ_1 [−]	−2865	φ_2 [−]	6360
τ_1 [−]	4.344	τ_2 [−]	1.127
γ_1 [−]	0.8624	γ_2 [−]	0.07969

Table 1.
Constants of Jurinak model for the evaluation of desiccant unit.
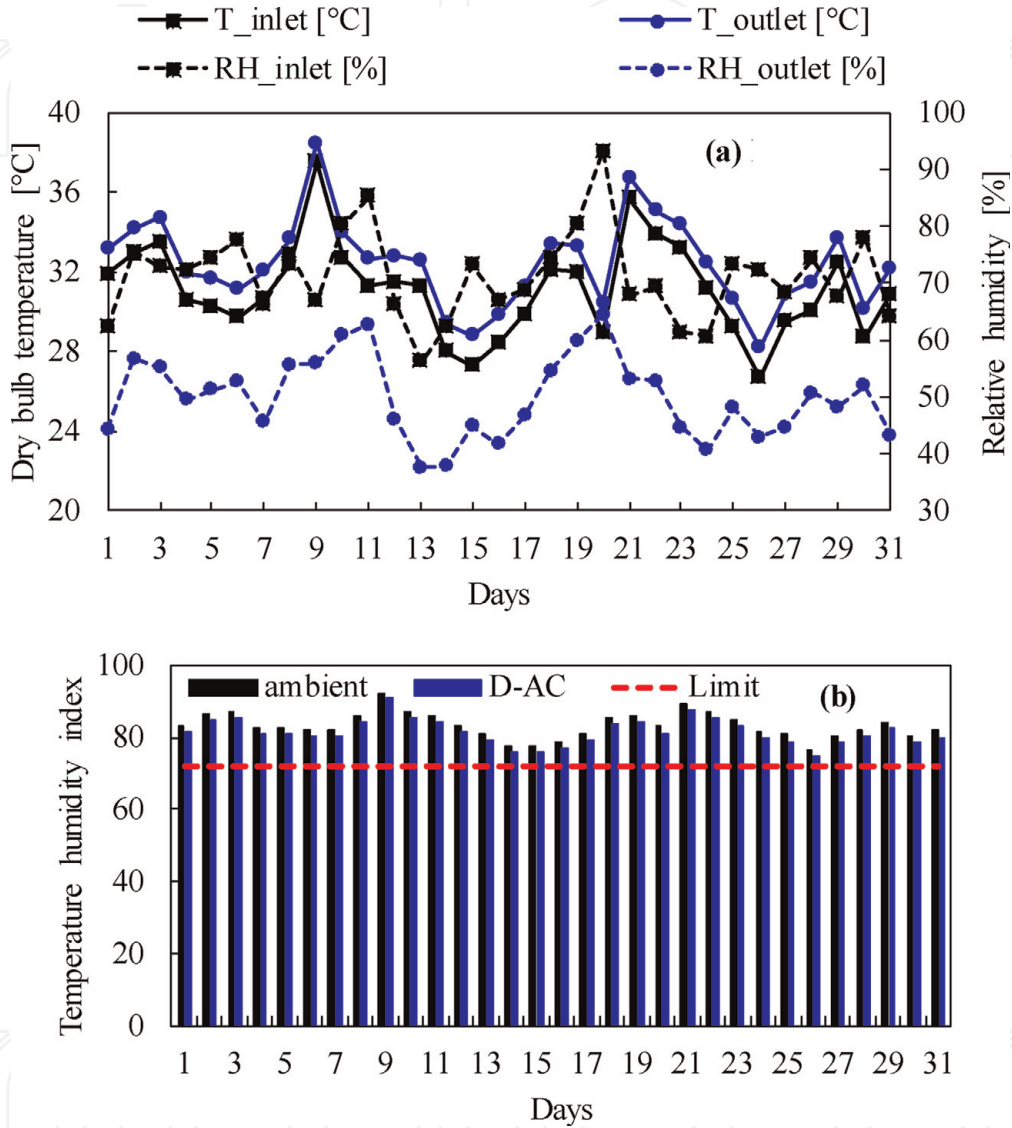
Figure 6.
Results of D-AC system for July (daily-basis) for climatic conditions of Multan, Pakistan: (a) temperature-humidity profile and (b) THI profile.

the dehumidified air after passing through the desiccant and the T_1 is the ambient air temperature (°C).

Figure 6 shows the results of the standalone D-AC system for July (daily based) according to climatic conditions of Multan, Pakistan. The data of temperature and humidity is the average data of 20 years obtained from the METRONOME software. The D-AC is evaluated in terms of system analysis and also THI analysis which elucidate the D-AC system's applicability for animal air-conditioning. **Figure 6a** shows the difference between ambient air temperature and relative humidity with the product air temperature and relative humidity. It is clear that the product air temperature is higher than ambient air temperature due to latent heat of adsorption [15, 29, 30]. However, relative humidity of product air from the D-AC system is

lower than ambient air relative humidity due to adsorption of water by desiccant material. Feasibility of the standalone D-AC system for animal air-conditioning is checked by the THI analysis which clarifies the system's feasibility for desired application. **Figure 6b** shows the THI values of ambient and product air, as well as the permissible limit of heat stress. The permissible limit of heat stress for cows is 72. The THI of the ambient air as well as product air is higher than the permissible limit for the whole month. So, it may not be suitable for the ambient conditions of Multan for the month of July.

4.2 M-cycle assisted desiccant air-conditioning (M-DAC) system

The schematic diagram of Maisotsenko cycle (M-cycle) assisted desiccant air conditioning (M-DAC) system is shown in **Figure 5b**. It consists of desiccant unit with the addition of HX and an exclusive M-cycle unit. The M-cycle cooling device lowers down the temperature of the processed air from the HX. Therefore, this system can be used for the humidity and temperature control. This can be efficient in hot and humid climatic regions where temperature and humidity control are essential. It may also be efficiently feasible for the applications in which humidity and temperature control is concerned (i.e., agricultural storage and livestock applications) even in hot and humid climatic conditions [5, 11, 16, 26]. The system consists of two desiccant blocks (DB-1 and DB-2) used for the air dehumidification and regeneration purposes. The dehumidified air is passed through the heat-exchanger where the temperature of the air becomes nearly equal to the ambient air. The air is further passed through the M-cycle unit where air is further cooled up to the desired temperature and humidity conditions to be used for desired application. The desiccant unit is regenerated by hot air and therefore a heating unit is principally required in this system which is supposed to be operated on low-cost thermal energy options. The heated air is passed through the desiccant unit to remove moisture from the desiccant material for cyclic usage.

It is important to mention that the M-cycle is an advanced indirect evaporative cooling conception that cools down the temperature of the working air up to the dew point by capturing energy from the air step by step as the humidity of the system remains constant [5, 16, 31, 32]. M-cycle is well-known in the air-conditioning field due to its working range for the dew point evaporative cooling. The details can be found from authors' previous work as reported in [16]. Many researchers used different structures (channels) and materials for the manufacturing of the M-cycle channels as well as flow arrangements [8, 16, 31, 32]. In one-way configuration of M-cycle unit, the ambient air is passed through the dry channels (in cross flow direction to the wet channel) and then part of this air is mixed into the wet channel. The cyclic process brings the product air temperature to the dew point (theoretically) of the ambient air temperature. In another way configuration of M-cycle unit, the wet channel is sandwiched between two dry channels. Process air is passed firstly through one of the dry channels followed by the wet channel. In the cyclic process, this will lower the temperature of the product air passing through the other dry channel up to the ambient air wet bulb (finally approaches to the dew point) temperature. In authors' previous work [5], a simplified correlation was developed for performance evaluation of the M-cycle unit as given by following Eqs. (18) and (19):

$$T_o = A_1 + B_1(T_i) + C_1(H_{spc}) \tag{18}$$

$$Q = A_2 + B_2(T_i) + C_2(H_{spc}) \tag{19}$$

where T_i and T_o represent the air temperature (°C) at inlet and outlet of M-cycle channels, respectively. The term H_{spc} represents the specific humidity (g/kg-DA) and Q represents the specific cooling capacity. The terms A, B, and C are the constants for simplified correlations, and optimized values for these constants are given in **Table 2**.

Figure 7 shows the daily based analysis of M-cycle based D-AC system for the month of July for Multan, Pakistan. The data of temperature and humidity is the average data of 20 years obtained from the METRONOME software. The M-DAC is

Constant	Value	Constant	Value	Constant	Value
A_1 [−]	6.70	B_1 [−]	0.2630	C_1 [−]	0.5298
A_2 [−]	−5.48	B_2 [−]	0.7317	C_2 [−]	−0.5946

Table 2.
*Numerical values of the constants of the simplified M-cycle correlations [5].*
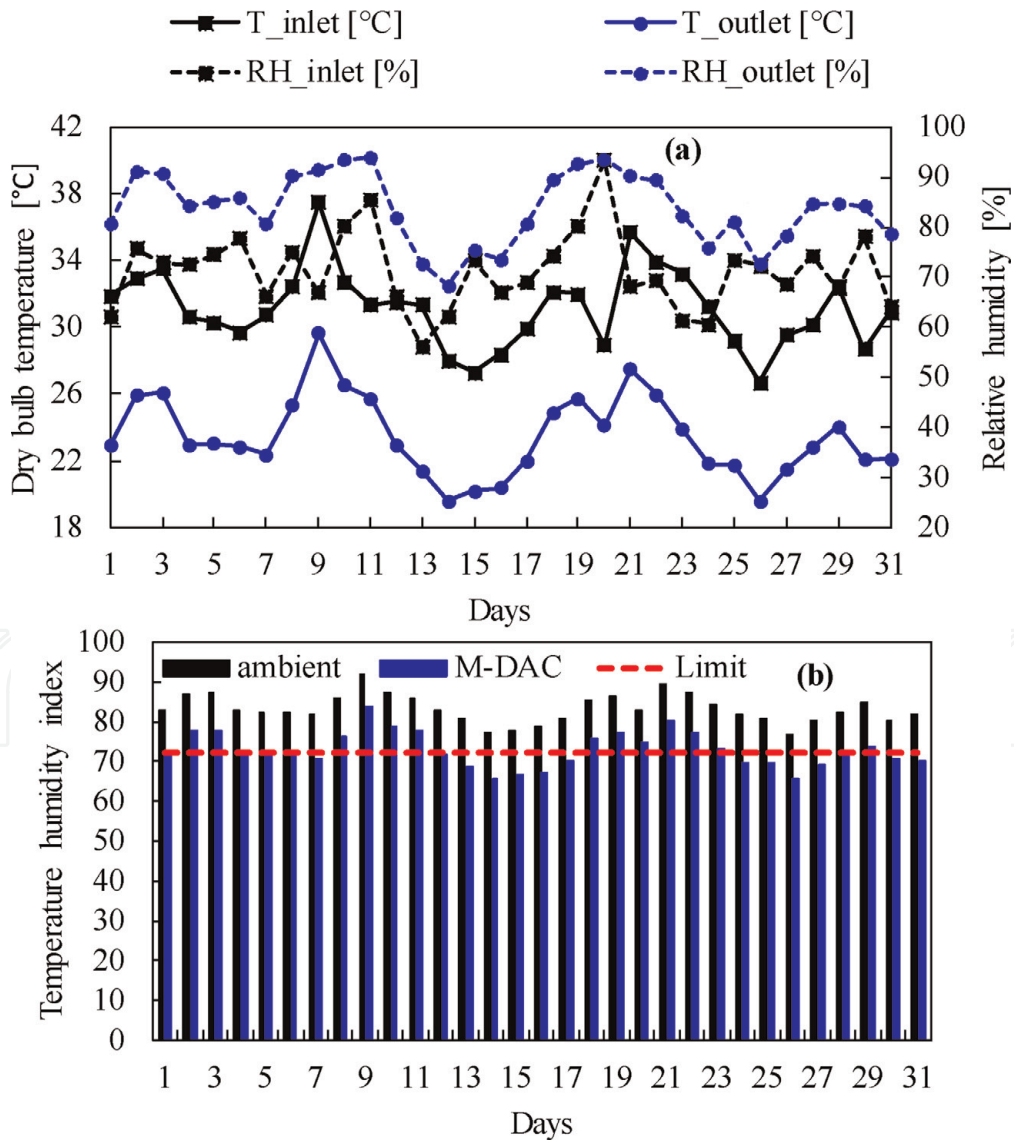
Figure 7.
Results of M-DAC system for July (daily-basis) for climatic conditions of Multan, Pakistan: (a) temperature-humidity profile and (b) THI profile.

evaluated in terms of system analysis and THI analysis which elucidate the M-DAC system's applicability for animal air-conditioning. **Figure 7a** shows the difference between ambient air temperature and relative humidity with the product air temperature and relative humidity. It is clear from the figure that the product air temperature is lower than ambient air temperature due to water evaporation [30, 33–35]. However, relative humidity of product air is higher than ambient air relative humidity which is required for animal air-conditioning.

Thereby, feasibility of the M-cycle based D-AC system for animal air-conditioning is checked by THI calculated from Eq. 9. **Figure 7b** shows the THI values of ambient air and product air, and permissible limit of heat stress is also shown in the figure. The permissible limit of heat stress for cows is 72. The figure clearly indicates that the THI of the ambient air is higher than the permissible limit for the whole month, while the THI of the product air is lower than permissible limit in most of the days. So, it may be feasible for the ambient conditions of Multan for the month of July (greater relative humidity and temperature).

The psychrometric representation of the product air of proposed AC systems according to the temperature and relative humidity values is shown in the **Figure 8** with the help of different markers. The values are obtained for the ambient conditions of Multan, Pakistan for the month of July. The black color line box shows the thermal comfort zone for animals. The circular marker shows the ambient air conditions, triangular marker shows the D-AC system's air conditions and diamond shaped marker shows M-DAC system's air conditions. The ambient conditions and D-AC output conditions are not able to provide the thermal comfort for animals. However, M-DAC output conditions are relatively suitable; therefore, this system can be applicable for animal air-conditioning subjected to the conditions.
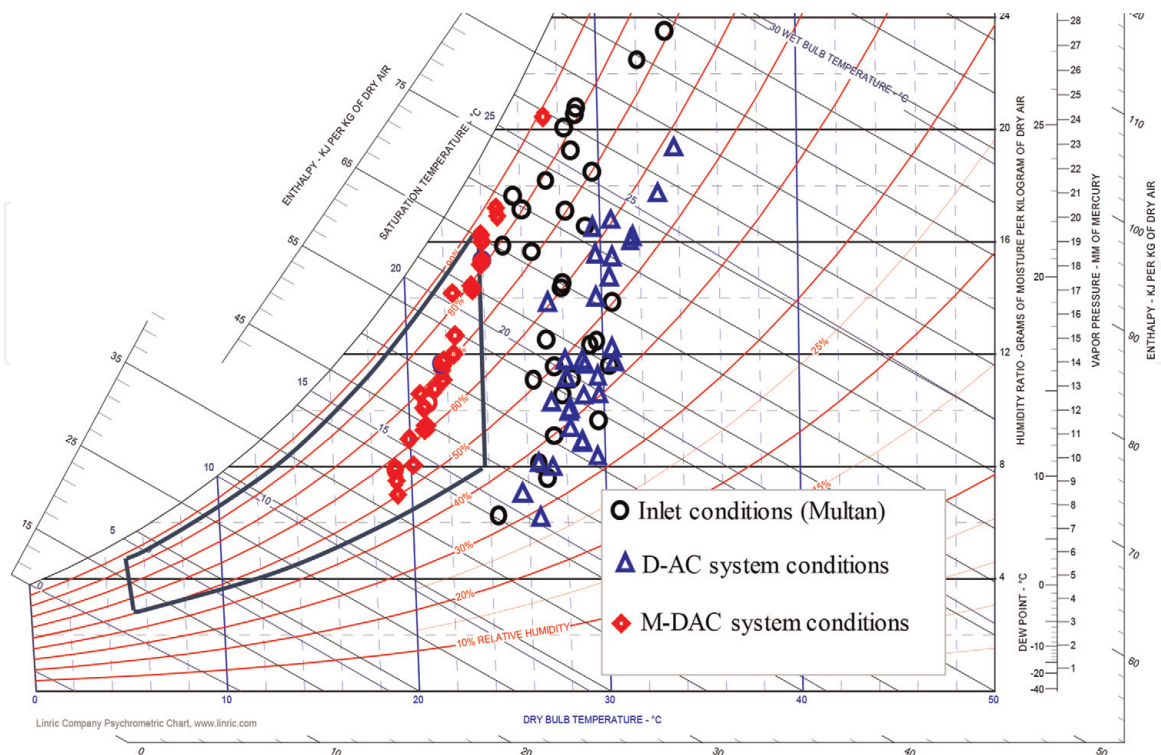
Figure 8.
Psychrometric plot of results identifying the feasibility of D-AC and M-DAC systems. Black line marked closed region shows animal air conditioning zone.

5. Conclusions

This chapter reviews the fundamental requirements for animals' air conditioning (AC) particularly for developing countries. The significance of ventilation rate and the associated animal housing designs are discussed from the view-point of energy-efficient climatic control systems. The study explores the literature related to temperature humidity index for Holstein Friesian cows. The importance of evaporative cooling systems is obvious in developing countries; however, this chapter highlights its usage/integration with the thermally-driven desiccant based open cycle systems. In this regard, the study focuses the climatic conditions of Multan, Pakistan. The performance of two kinds of evaporative and desiccant based AC systems is checked for the subjected application. Results indicate that the performance of the systems vary with the climatic conditions and systems' operation. The standalone desiccant AC (D-AC) system nicely dehumidifies the air which increases the temperature as well due to adsorption heat. However, the dry warm air is unable to provide the optimum thermal comfort conditions for the animals for most of the climatic conditions. However, M-cycle assisted desiccant AC (M-DAC) system dehumidifies the air on one side whereas it also control the sensible AC load on the other side. Thus, it makes it feasible to provide thermal comfort conditions for animals for most of the climatic conditions. Thus, it is energy efficient to use the evaporative cooling options in humid climates if integrated with desiccant units. The D-AC system should be used only for humid climatic conditions where latent load control (dehumidification) is mainly required. The D-AC system is not found effective for the summer conditions of Multan, Pakistan. However, it may be used for drying purposes as per authors' previous work. The M-DAC system is good to use in all kind of humid climatic conditions including the hotter regions. It has been found feasible for thermal comfort of cows for summer conditions including rainy season for Multan, Pakistan.

Conflict of interest

The authors declare no conflict of interest.

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