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Wet-Bulb and Dew-Point Evaporative Cooling Options for Poultry Sheds

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Abstract: *The present study addressed the applicability of evaporative cooling (EC) systems for poultry birds. In summer, climatic conditions are not favorable for the thermal comfort of poultry birds. Cooling systems available in the market are not energy efficient and cause global warming. Evaporative cooling systems are energy-efficient, low-cost, and environment-friendly options for the thermal comfort of poultry birds. Three kinds of EC systems: direct, indirect, and Maisotsenko cycle-based evaporative cooling (DEC, IEC, and MEC) systems are studied for poultry houses. The performance of the systems is investigated in terms of wet-bulb effectiveness. Temperature-humidity index (THI) is also calculated based on output results to check the thermal comfort of the poultry birds. According to the results, the MEC system performs better as compared to the old DEC and IEC systems. However, the performance of the systems is limited in humid areas.*

Keywords: evaporative cooling, M-Cycle, temperature-humidity index, poultry sheds, Pakistan

1. INTRODUCTION

Pakistan is an agricultural country that contributes 21 % of gross domestic product (GDP) and absorbs half of the labor strength to reduce the poverty in rural areas [1]. Livestock is a subsector of agriculture that contributes 11.4 % of agriculture GDP. Pakistan is the 11th largest poultry producer in the world and provides 1.6 million employments (Pakistan economy survey). Poultry meat contributes 34 % of the total meat production of Pakistan [2]. Table 1 shows the production of poultry birds and poultry meat annually in Pakistan for the last 10 years. From an economic point of view, poultry has huge importance in Pakistan. However, in Pakistan every year several flocs are destroyed due to undesired environmental conditions in poultry sheds [2]. Therefore, it is necessary to provide suitably controlled conditions in poultry sheds for healthy growth in poultry sheds [3].

Table 1. Production of poultry birds, and poultry meat in Pakistan (according to the economic survey of Pakistan 2018-19) [4]

Years	Poultry Birds [Million numbers]	Poultry meat [000 Tonnes]
2010	610	707
2011	633	767
2012	721	834
2013	785	907
2014	855	987
2015	932	1074
2016	1016	1170
2017	1108	1276
2018	1210	1391
2019	1321	1518

Temperature (T) and humidity control are necessary for the thermal comfort of poultry birds [5]. Air-conditioning systems are used worldwide to control the temperature and humidity in a controlled environment. Mechanical

compressor-based air-conditioning (VCAC) is used worldwide. VCAC system consumes high primary energy and causes global warming. Evaporative cooling systems could be an energy-efficient and environment-friendly solution for poultry application. In this study, three kinds of evaporative cooling systems are proposed to check the applicability of the systems for poultry thermal comfort. In addition, temperature humidity index (THI) and the heat stress is also calculated and check their relationship with a live weight of poultry bird.

2. MATERIALS AND METHODS

2.1 PROPOSED EVAPORATIVE COOLING (EC) OPTIONS

Evaporative cooling (EC) is the ancient technique that used sensible heat of air to evaporate water [6]. In this process, liquid water is converted into water vapors by using thermal energy present in the air [7]. Evaporative cooling is a low-cost, energy-efficient technology for air-conditioning (AC). The systems consume one-fourth of electricity as compared to available conventional compressor-based air-conditioning systems (VCAC) [8]. The performance of EC systems depends on ambient air conditions. According to the literature, there are three types of EC systems: direct evaporative cooling (DEC) systems, indirect evaporative cooling (IEC) systems, and Maisotsenko-Cycle based evaporative cooling (MEC) system.

Direct evaporative cooling (DEC) is a constant enthalpy process in which humidity [g/kg DA] increases and temperature decreases simultaneously [9]. In the DEC system, ambient air directly contacts with water and during this process, ambient air sensible heat is converted into latent heat [10, 11]. An increase in humidity level causes discomfort and it is the key limitation of the DEC system [12–14]. Indirect evaporative cooling is a constant humidity process in which ambient air temperature decreases without the addition of moisture/humidity in the air [15, 16]. In this process, the air is not directly in contact with water. IEC system consists of two types of channels (wet and dry channel) and cooling effect

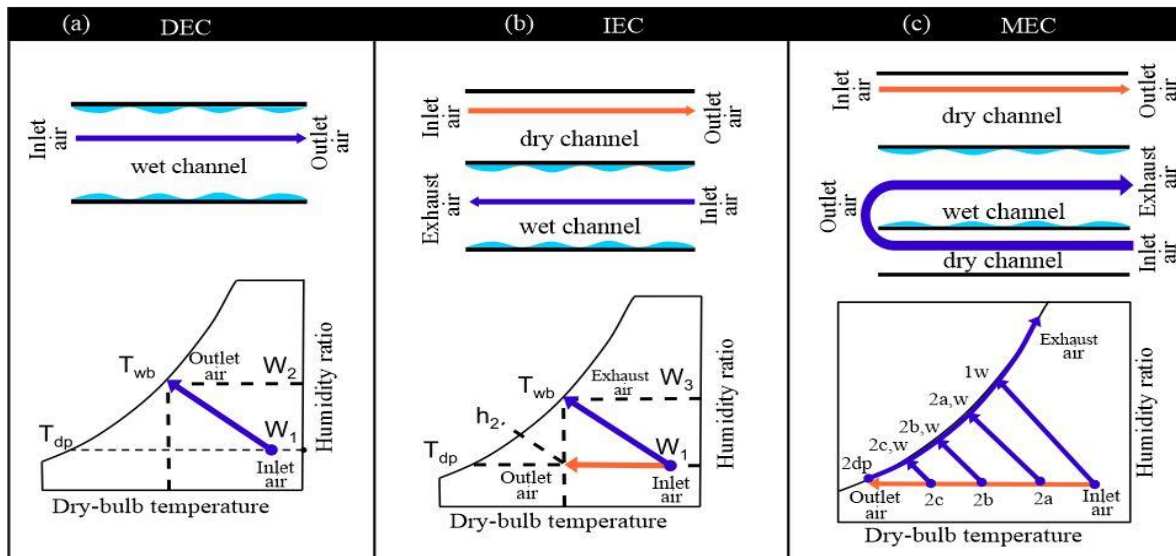


Fig. 1 Schematic and psychrometric representation of DEC, IEC, and MEC systems [2].

is produced due to two thermodynamic processes: evaporative cooling and sensible cooling [1]. DEC and IEC systems cool the air up to wet-bulb temperature therefore the performance of the systems is limited up to wet-bulb temperature [17]. Maisotsenko-Cycle evaporative cooling (MEC) is the advanced form of the indirect evaporative cooling system. It is also called a regenerative cooling system. The working principle of the MEC system is the same as the IEC system however it can reduce the temperature of air below wet-bulb temperature and closer to dew-point temperature (ideally up to dew point temperature) [18], [19]. The performance of the MEC system is calculated in terms of dew-point effectiveness. Schematic and psychrometric representation of DEC, IEC, and MEC systems is shown in Fig. 1.

2.2 Mathematical equations

According to literature, heat production in poultry birds varies with their body weight. Sheila T. Nascimento 2017 equation (1) is used to calculate the HP of poultry birds against their body weight [20]. Pedersen's (2000) mathematical model is used to calculate the sensible and latent heat production per bird with their live weight at different ambient temperatures [21]. There are equations (2a) and (2b) are mentioned below. However, Temperature Humidity Index (THI) for broilers is calculated by using equation (3) [22]. Equation (4) is used to calculate the wet-bulb temperature [°C] [1], and equations (5) and (6) are used to calculate the wet-bulb and dew-point effectiveness of the systems [1].

$$HP = 60.64 + 0.04LW \quad (1)$$

$$Q_t = 9.84m_a^3(4.10 \cdot 10^{-5}(20 - t_{db})^3 + 1) \quad (2a)$$

$$Q_s = 0.83Q_t(0.8 - 1.85 \times 10^{-7}(t_{db} + 10)^4) \quad (2b)$$

$$THI = 0.85T_{db} + 0.15T_{wb} \quad (3)$$

$$T_{wb} = T \tan^{-1} \left[0.151977 + (RH + 8.313659)^{\frac{1}{2}} \right] + \tan^{-1}(T + RH) - \tan^{-1}(RH - 1.676331) + 0.00391838RH^{\frac{3}{2}} \tan^{-1}(0.023101RH) - 4.686035 \quad (4)$$

$$\epsilon_{wb} = \frac{T_{in} - T_{out}}{T_{in} - T_{wb}} \quad (5)$$

$$\epsilon_{dp} = \frac{T_{in} - T_{out}}{T_{in} - T_{dp}} \quad (6)$$

where HP is heat production [W/kg], LW is live weight [g], Q_t is total heat production [J/s], Q_s is sensible heat produced [J/s], m_a is mass per live bird [kg], T_{db} is dry bulb temperature [°C], T_{wb} is wet-bulb temperature [°C], RH is relative humidity [%], ϵ_{wb} is wet-bulb effectiveness and ϵ_{dp} is dew-point effectiveness.

3. Results and Discussion

In this study, different types of evaporative cooling (EC) systems are developed on a lab-scale in Agricultural Engineering Department, Bahauddin Zakariya University Multan, Pakistan, and check the feasibility of the systems for thermal comfort of poultry birds. Figure 2 shows the annual climatic conditions of Multan, Pakistan. It shows that climatic conditions in the following months of summer (April to June) are hot and dry whereas July to October is hot and humid, which recommended a need for AC.

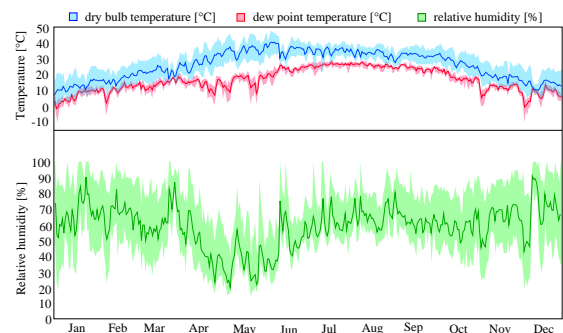


Fig. 2 Ambient Climatic Conditions of Multan Pakistan [6].

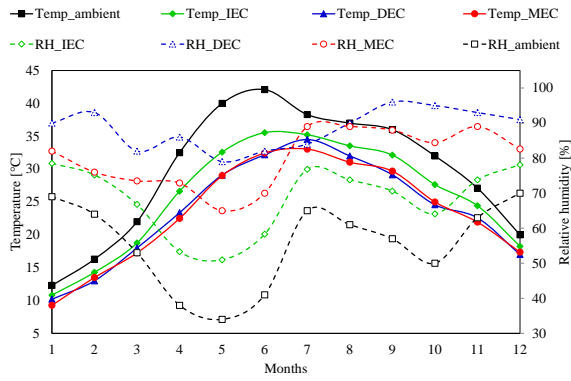


Fig. 3. Temperature and Relative humidity profile for ambient air and product air of DEC, IEC, MEC system [1].

The proposed EC systems reduce the temperature of ambient air and increase relative humidity. Figure 3 represents the variation in temperature and relative humidity profile for ambient air and product air of DEC, IEC, MEC systems. It is noticed that the performance of the developed systems depends on ambient air conditions. The systems' performance is higher under hot and dry climatic conditions however limited/lower under humid areas/monsoon season. Figure 3 also shows that the DEC and MEC systems perform better as compared to the IEC system.

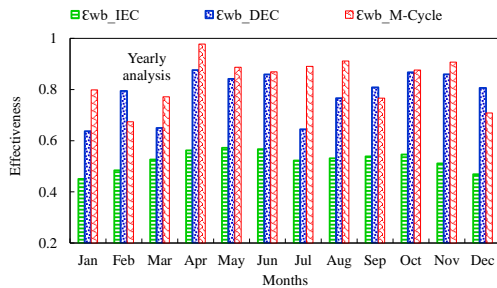


Fig. 4. Effectiveness variation in DEC, IEC, and MEC systems [1].

Figure 4 shows the performance varies based on the wet-bulb effectiveness of DEC, IEC, and MEC systems. From the figure, it is noticed that the wet-bulb effectiveness of the MEC system is higher as compared to DEC and IEC systems. Figure 5 shows the effect of the live weight (LW) of poultry birds on heat production (HP) and temperature-humidity index (THI). From this figure, it is noticed that the HP increased with an increase in LW and maximum when poultry birds reached a mature age. THI decrease with an increase in LW, which justifying the

statement regarding the use of heaters for one-week-old chicks.

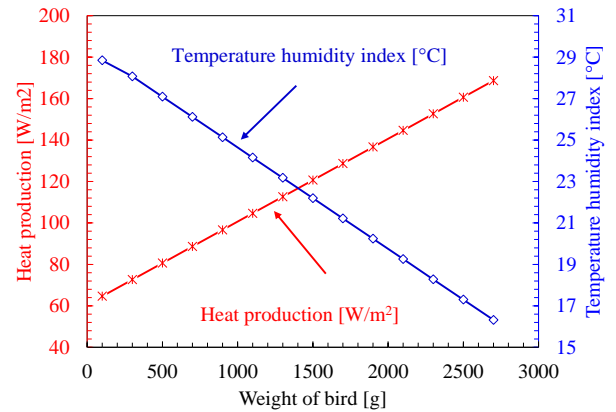


Fig. 5. THI and HP variations for the weight of poultry birds [1].

Pedersen's model generates heat production values against the live weight of poultry birds at different ambient temperatures. Figure 6 represents the variations in heat production values against the weight of poultry birds at different temperatures. It is noticed that at lower temperatures sensible heat (SH) is higher as compared to latent heat. At higher temperatures, latent heat increases as compared to sensible heat which causes suffocation in poultry birds due to a rise in the humidity level in the air. At this level, the gap between sensible and latent heat production is minimum which shows that the birds are near to expire.

THI index is of prime concern for the survival of poultry birds. From the literature, it is studied that these birds grow healthier in the temperature range of 18 °C to 29 °C with a constant relative humidity value of 50 % [22]. At the values of 30 °C temperature and 50 % relative humidity, the permissible limit of THI is defined. From 7 shows the Variation in the temperature-humidity index of ambient air and product air of DEC, IEC, and MEC system for climatic conditions of Multan Pakistan. From this figure, it is seen that the THI value of ambient air is within the threshold limit from November to March which indicates that there is no need for AC for the growth of poultry birds. In the remaining summer months (April to October) of Multan, AC is required for poultry birds. In this season, the permissible limit of THI is crossed by ambient air. EC systems are investigated for the thermal comfort of poultry birds in these months. it is noticed that DEC and

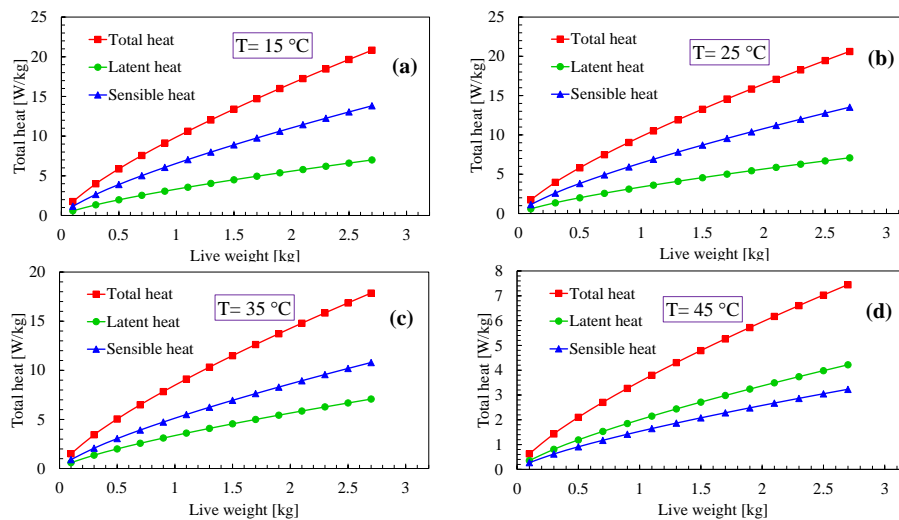


Fig. 6. Sensible and latent heat production for the live weight of poultry birds at different temperatures [1].

Table 1 Feasibility of EC options for poultry birds under climatic conditions of Multan Pakistan [1].

Months	Evaporative cooling systems		
	DEC	IEC	MEC
Jan	✓	✓	✓
Feb	✓	✓	✓
Mar	✓	✓	✓
Apr	✓	✓	✓
May	✓	✗	✓
Jun	✗	✗	✗
Jul	✗	✗	✗
Aug	✗	✗	✓
Sep	✓	✗	✓
Oct	✓	✓	✓
Nov	✓	✓	✓
Dec	✓	✓	✓

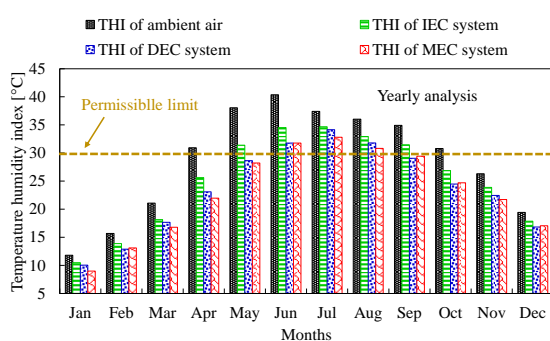


Fig. 7. Variation in the temperature-humidity index of ambient air and product air of DEC, IEC, and MEC system for climatic conditions of Multan Pakistan [1].

MEC performs better as compared to the IEC system. Table 2 shows the Feasibility of EC options for poultry birds under climatic conditions of Multan Pakistan on the base of THI numeric values. It shows that the DEC system is not feasible for June, July, and August. IEC system is not feasible from May to September. MEC system is not feasible for June and July. It shows that the MEC system is more feasible for climatic conditions of Multan Pakistan as compared to the DEC and IEC systems.

4. CONCLUSIONS

The study objective is to analyze the performance of different evaporative cooling systems under climatic conditions of Multan Pakistan. From the results, it is noticed that evaporative cooling systems (DEC, IEC, and MEC systems) are applicable for poultry birds. MEC system performs better as compared to DEC and IEC system. It is seen that these systems lower down the temperature while increasing relative humidity values to a greater extent simultaneously.

The weight of poultry birds with growing age increases and thus, heat production is increased. The relationship of heat production and THI index also indicates that young birds with less weight can accommodate high values of THI but the older birds with more gain in weight show remarkable stress to the environmental conditions in terms of ambient temperature and relative humidity.

Pedersen Model expressed that, there is a sharp linkage between the values of sensible and latent heat for increasing the weight of birds at different temperatures. When the temperature of ambient air increases from body temperature of poultry bird, latent heat production rise from sensible heat production and cause of suffocation. Results conclude that evaporative cooling systems need to minimize the value of relative humidity during the hot

and dry months to meet the permissible limit of the THI index for poultry birds. This condition can be satisfied once a hybrid evaporative cooling system is developed. Maisotsenko-Cycle assisted desiccant air-conditioning system could achieve the desired conditions for thermal comfort of poultry birds.

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