Evaporative Cooling Systems for Thermal Comfort of Foreign Cattle Breeds: THI Evaluation and System Feasibility

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Evaporative Cooling Systems for Thermal Comfort of Foreign Cattle Breeds: THI Evaluation and System Feasibility

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ABSTRACT: *Agriculture is an important economic sector for developing countries. It is providing food, fiber and energy to the increasing human population. In developing countries like Pakistan, livestock is the main source of livelihood for majority of the rural population. As compared to research on crop production and the effect of climate on livestock production systems, or how they can adapt to changes is rarely studied. In climate change affected Pakistan, the milk production of foreign breeds is highly affected by the heat stress. The sternness of heat stress conditions in high-yielding dairy cows is currently underestimated. The present study investigates the system feasibility and evaluation of temperature-humidity index (THI) for foreign breeds of cattle under interior climatic zone in Multan. To achieve the thermal comfort for high productive breeds of cattle, different types of vapor compression (VCAC) air conditioning system are used worldwide. These systems consume large amount of primary energy and contribute directly to global warming. To overcome this problem, low-cost evaporative cooling system has been studied and designed for thermal comfort of livestock applications and the feasibility of these systems are checked for the climatic condition of Multan. The expected climate changes that can affect the livestock population and milk production was studied in present study and a possible option for long term planning has been discussed.*

Keywords: climate change, agriculture, livestock, THI, evaporative cooling

1. INTRODUCTION

By raising the world growth, people seek to enhance their living standards and improving their work performance. The basic need of primary energy increase by the increase of world population. Energy use has grown rapidly worldwide increased focus on energy supply difficulties, Inadequate energy resources and negative effects such as Global warming, climate change, ozone depletion. So, the need of air conditioning becomes an essential problems in terms of schools, colleges, offices, shopping malls, buses and trains. Average energy consumption increases by 10% per person, while the global population continues to grow by 27%. Such basic energy consumption and CO_2 emanations have increased by 49% and 43%, correspondingly [1], [2].

Food and energy shortage are the serious problems of developing countries like Pakistan. Pakistan is agricultural country and the share of agriculture in GDP is 18.9%. Out of that the livestock contribute 59% [3] The agriculture sector is expected to be severely affected in upcoming years. Main climatic change parameters such as temperature, humidity and radiation changes are very important factors affecting the breeding and reproductive capacity of livestock [4]. Animals health and their fertility affected by the climatic condition Heat stress is produced by the physical movement and digestion of animals [5]. The environmental impacts are involved in heat stress are wind speed, temperature of air, solar radiation and relative humidity [6]. The production concert of animal is highly affected by heat stress [7]. Global macroclimate variation is primarily fueling greenhouse gas (GHG) emanations, which consequences in bimetallic strip [8].

According to the IPCC's view, fluctuating climate can cause various environmental complications such as famine, torrents and health risk [9]. Similarly, it has been assessed that the average temperature in the late 2100s may increase to 1.4°C -5.8°C [10] In high yielding animals the production percentage is mainly depend on the climatic condition. The dairy cattle are highly sensitive to the hot environment. If the climatic zones are severe its effects on the metabolic and respiration rate that's are proportional to the level of production [11]. The heat stress risk can be estimated by temperature humidity index method by using climatic parameters [12].

Additionally, climate change can also cause unexpected outbreaks in temperature and precipitation patterns which cause novel ailments in livestock. Adequate temperature, and rainfall have diverse direct effects on climate change. livestock are expected to have adverse effects on both direct and indirect effects of climate change that affect their productivity [13]. These latent ecological pressures cause the disturbance of livestock development, health production and generative functions.

Farmers in Pakistan are less aware from the factors that creating animals' health problems. Pakistan is also facing the energy problems so there is necessary to launch the energy efficient technology which fulfill the need of thermal comfort for humans and non-humans [14]. For this purpose, many heating ventilation air conditioning systems has been system has been used in worldwide. These systems consume large amount of energy and contribute in global warming [15].

So, there is necessary to launch the energy saving system many researchers' studies to introduce the energy efficient and environmentally friendly system, the evaporative cooling system has been launched to overcome this problem. These systems prove environment friendly and consume less amount of energy This system simultaneously control the humidity and temperature[16]. As compared to HVAC system these systems do not produce chlorofluorocarbons (CFCs) carbon which cause the depletion of ozone layer. Therefore, evaporative cooling system is good selection in dry and hot regions for animals' thermal comfort. The objectives of this study are

- Evaluate evaporative cooling system for thermal comfort of foreign breeds of cattle
- Check the feasibility of system in hot and dry regions, like Multan, Pakistan.

2. EVAPORATIVE COOLING OPTIONS

The evaporative cooling is an age told technique which uses latent heat of evaporation of water vapors to produce cooling effect. This system needs heat to transform the water into vapors therefore the surface contact becomes cool due to evaporation Evaporative cooling system was primarily familiarized in 1980s into china. EC performance is expressively prejudiced by means of the outdoor air surroundings. This system is applicable for air cooling and handling in ventilation system and air conditioning system. The most populated countries like china is suffering into socioeconomic revolution. From last three decades living standards of people intensely increased. Rapid increase in population cause the huge consumption of energy

The potential of evaporative cooling system can be measured by the evaluation of air-dry bulb temperature and wet bulb temperature. Grater the evaporative cooling effect when grater the difference between two temperatures. The evaporative cooling system can be classified into two sorts, such as water cooling and air cooling. In first sort, the water is cooled by sensible cooling because of difference between temperature of ambient air and cooling water. When the water temperature is greater than the ambient air then the cooling occur is known as sensible cooling. Industrial process and air conditioning, cooling tower utilize in power plant and water-cooled refrigeration's are the applications of this sort [17].In air cooling sorts, the air is cooled by evaporation of small quantity of water ,generally on warm days. This is adiabatic process because in this case, the sensible heat is changed into latent heat. This class of evaporative cooling contains such applications, greenhouse cooling, livestock, poultry and hog cooling, product storage and warehouse cooling, nursery cooling and (dry cooler ,gas turbine) inlet air precooling.

There are three types of evaporative cooling system

- Direct evaporative cooling (DEC)
- Indirect evaporative cooling (IEC)

Maisotsenko evaporative cooling (MEC).

2.1 Direct evaporative cooling system

Direct evaporative cooling (DEC) system is easiest and oldest process of evaporative cooling. Evaporative cooling system consist of pads materials, water tank, pump , fan and sprinklers. Water uplift through water pump into the sprinklers and distribute into pad materials as shown in fig 1. The cellulose pad material has been used in this study. Ambient air is pass through pad materials and directly contact with water. To begin the process air is driven by fan from channel. Due to mass and heat exchange among air and water falling, the process air become cold and humid. The water is recycled again and again, and temperature of recycled water reduce approximately 5^{o}c as compared to water ambient temperature. The vaporization heat is extract from hot and dry air which becomes cold [18].

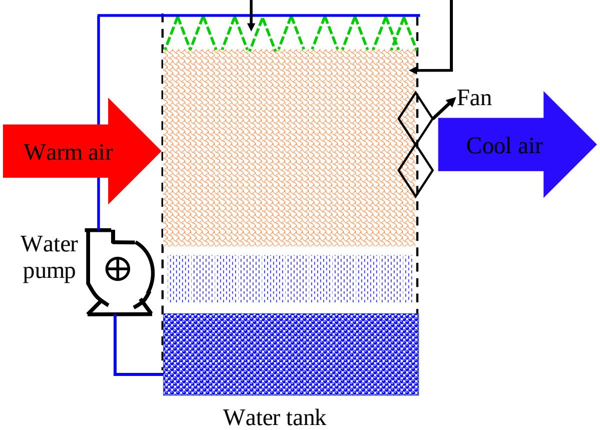

Fig. 1. Schematic demonstration of direct evaporative cooling system

Direct evaporative cooling system is an adiabatic process. It works on the principal of swamp color. In this system enthalpy remains constant, relative and specific humidity increase, and temperature decrease as shown in fig 2.The effectiveness of DEC ranges from 75% to 85% [19].

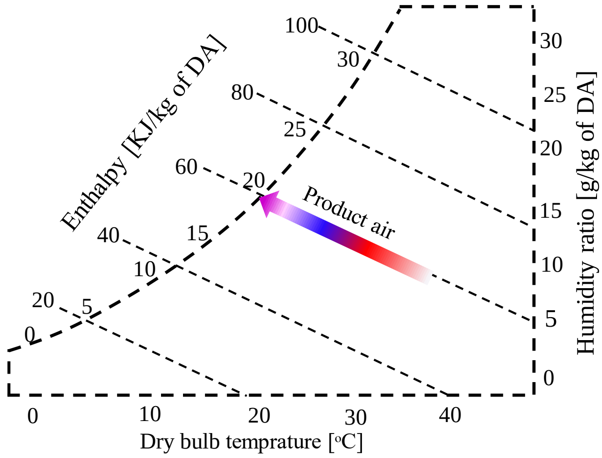

Fig. 2. Psychrometric representation of direct evaporative cooling system

2.2 Indirect evaporative cooling

Indirect evaporative cooling system work on the same principle of direct evaporative cooling system but here air and water are not directly contact. It cools the air by evaporation of water. It evades the usage of refrigerants, vapor compressor, cooling towers, chlorofluorocarbons and cooled and chilling water tubes which eradicates the predictable substructure of mechanical or thermally driven coolers up to 75%. Heat exchanger is used in system to cold hot and dry air which provides into living space. In this process heat removed by clean water which exploits the evaporation of air.

Indirect evaporative cooling system consists water tank, fan, water pump for driving water to the sprinkles which is mounted on top and two channels (wet channel and dry channel). Wet channel is for passage of water and dry channel is air. These channels are connected to each other by a layer that allows to transfer of heat between wet and dry passage. The schematic and psychrometric representation of indirect evaporative cooling system is shown in fig 3 and fig 4 respectively.

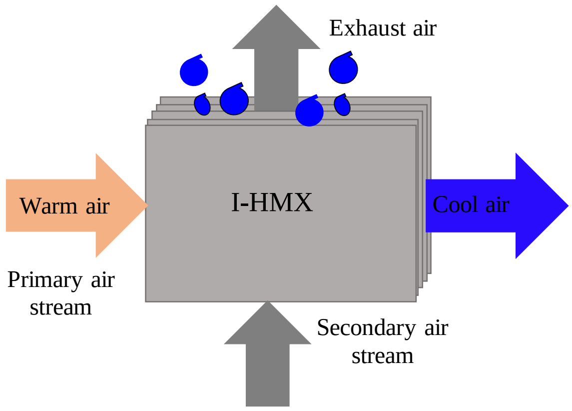

Fig. 3. Schematic diagram of indirect evaporative cooling system.

In IEC system humidity ratio remains constant, relative humidity increase, and enthalpy of system decrease with increase of dry-bulb temperature shown in fig 4.The effectiveness of IEC ranges from 55% to 65% [20].

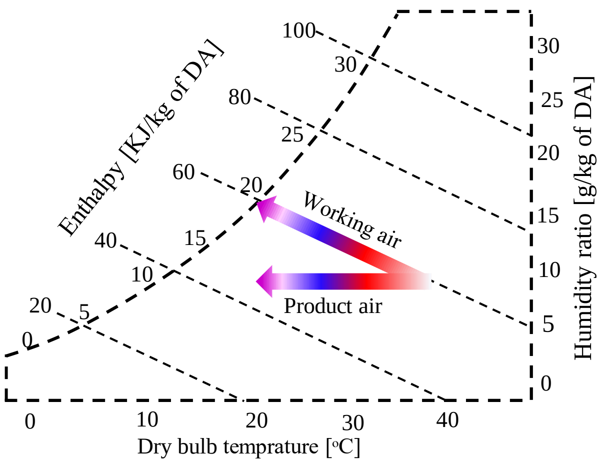

Fig. 4. Psychrometric representation of indirect evaporative cooling system.

2.3 Maisotsenko evaporative cooling

Maisotsenko evaporative cooling (MEC) system is the developed form of IEC system. It is also known as dew point evaporative cooling system because it decreases the dry bulb temperature up to dew point temperature. The Maisotsenko Cycle (M-Cycle) is a thermodynamic conception which captures energy from the air by utilizing the psychrometric renewable energy available from the latent heat of water evaporating into the air [21]. It can be used as cooler as well as humidifier. The popularity of this system in air conditioning field is due to its capability to reach the temperature of product air to the dew point temperature

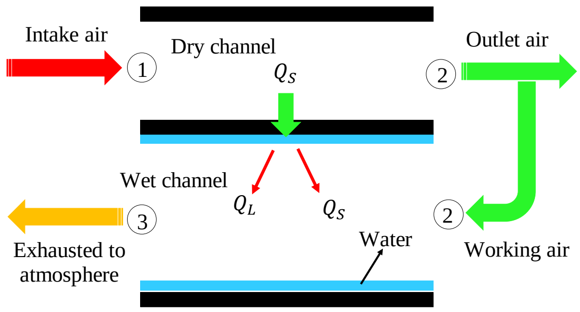

Fig. 5. Working principle of Maisotsenko cycle evaporative cooling system.

The working principle of modified Maisotsenko cycle is shown in fig 5.This system consists of three channels from which two are used for dry passage and one channel work as wet passage. The air is pass through the dry passage and its temperature decrease by surface contact with wet channel. Then this air pass through wet channel from which the evaporation process takes place and air becomes warm humid. This air then again passes through dry channel and becomes cool which used as conditioned air. This process take place again and again until the temperature of ambient air reach to dew point temperature. In this process the temperature of air decrease to dew point temperature [22].The psychrometric representation of Maisotsenko evaporative cooling system is shown in fig 6. The dew point effectiveness of MEC ranges between 65% to 75%.

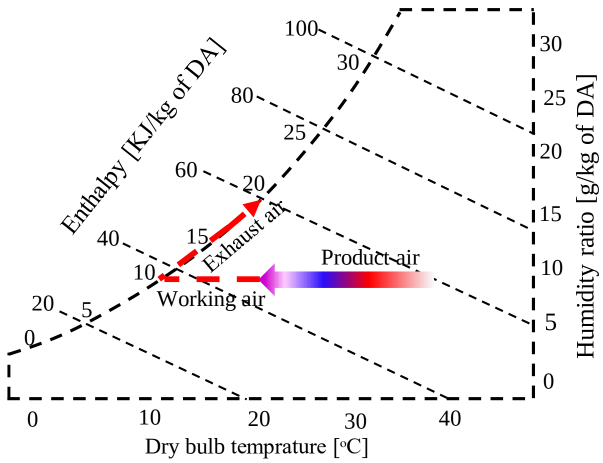

Fig. 6. Psychrometric representation of Maisotsenko cycle evaporative cooling system

3. METHDOLOGY

The wet bulb effectiveness of direct evaporative cooling system and indirect evaporative cooling system is the ratio of difference of inlet and outlet temperature to the inlet and wet bulb temperature. The wet bulb effectiveness can be calculated from following equation.

$$\varepsilon_{wb} = \frac{T_{in}-T_{out}}{T_{in}-T_{wb}} \qquad (1)$$

Where ε shows the effectiveness, T_{in}, T_{out}, T_{wb} represents the inlet, outlet and web bulb temperatures of air respectively.

Dew point effectiveness of Maisotsenko cycle evaporative cooling system is the ratio of inlet and outlet temperature of the system to the difference of inlet temperature and wet bulb temperature and can be calculated by following equation

$$\varepsilon_{dp} = \frac{T_{in} - T_{out}}{T_{in} - T_{dp}} \qquad (2)$$

ε shows the effectiveness, T_{in}, T_{out}, T_{dp} represents the inlet, outlet and dew point temperatures of air respectively

The enthalpy of evaporative cooling system is the combination of temperature and humidity. The equation 2 has been used for calculating the enthalpy of evaporative cooling system.

$$h = 1.006T + W(2501 + 1.86T) \qquad (3)$$

Here T represents the temperature which is either in Celsius or in kelvin. W shows the humidity ratio which is in gram per kilogram of dry air.

The foreign cattle breeds such as Holstein Frisian are severely affected by heat stress phenomena. High temperature declines the milk production, feed intake etc. Thermoneutral zone for livestock application can be calculated by temperature humidity index (THI). It is a relationship between temperature and relative humidity [23] Many formulas has-been used for measuring temperature humidity index but the commonly equation used for THI is

$$THI = (1.8T + 32) - [(0.55 - 0.005RH)(1.8T - 26) \qquad (4)$$

The temperature and relative humidity (RH) are in Celsius and percentage respectively [24]. The THI is equal to dry bub temperature when the RH is 100%. The cattle are known as in heat stress phenomena if the value of THI is greater than 72. The THI between 68 and 72 is necessary for the survival of foreign cattle breeds.

4. RESULTS AND DISCUSSION

In this section we discussed about the performance of evaporative cooling systems such as DEC, IEC and MEC for different ambient air conditions of Multan, Pakistan. Performance evaluation of evaporative cooling systems also have been evaluated for foreign cattle breeds in the climatic condition of Multan.

Fig 7 represents the temperature and relative humidity variation of ambient air and process air of evaporative cooling system. As the temperature is high the relative humidity is respectively lower. From the figure it has been clear that that increase in temperature results the decrease in the relative humidity vice versa.

The wet bulb effectiveness of direct evaporative cooling system and indirect evaporative cooling system and dew point effectiveness of Maisotsenko cycle evaporative cooling system can be relatively compare with different ambient air condition of Multan as shown in fig 8.

From the fig 8 we seen that the dew point effectiveness of MEC system is relatively better than the direct evaporative cooling system and indirect evaporative cooling. The effectiveness of DEC is better than IEC system. From the results it has been conclude that performance of MEC and DEC is better as compared to the IEC system.

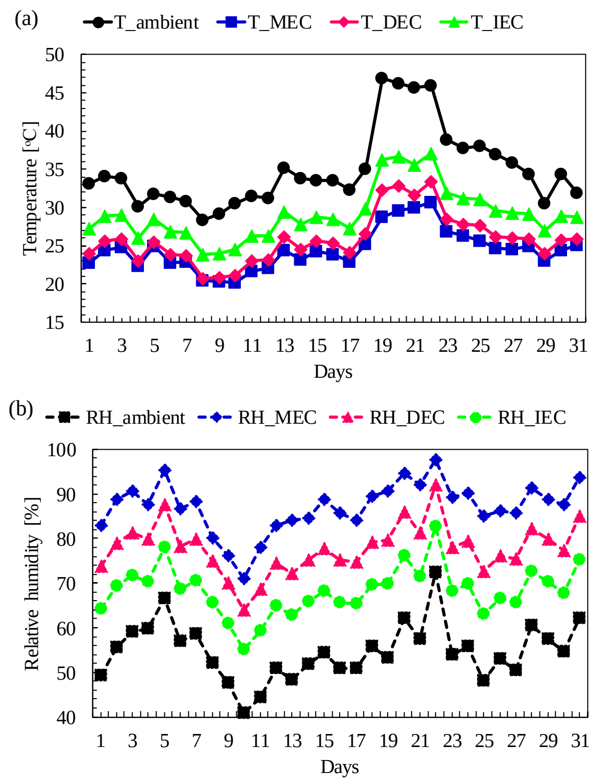

Fig. 7. Efficiency of evaporative cooling systems for variations in (a) temperature (b) relative humidity

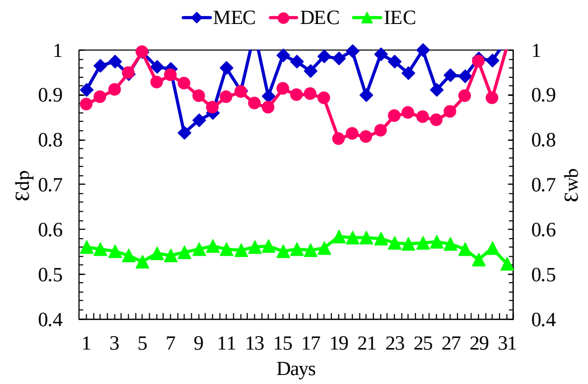

Fig. 8. Efficiency of evaporative cooling systems.

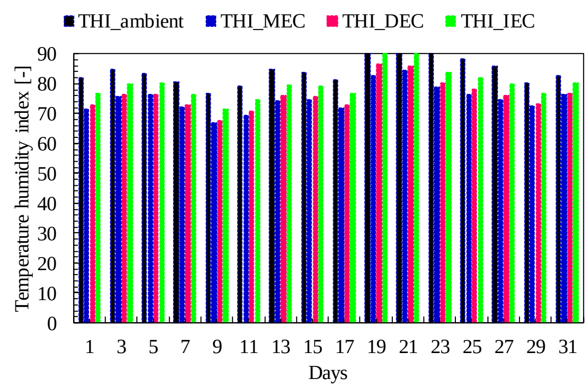

Fig. 9. Temperature humidity index of evaporative cooling systems for different ambient air conditions.

Temperature humidity index of evaporative cooling system can be calculated under several climatic condition. Fig 9 shows the relationship of temperature humidity index of evaporative cooling systems at different climatic conditions. Temperature humidity index less than 68 and greater than 72 is severe for the health of florigen cattle breeds. From the fig 9 we seen that THI of ambient conditions reached up to 90 which is severe for the health of foreign cattle breeds. The THI of MEC is relatively changes day to day. As compared to ambient THI the MEC THI is better. Similarly, the temperature of index of DEC system is fluctuate between 72 and 85. THI of IEC system is also greater than 72 like ambient condition. So, the performance of MEC system is better for thermal comfort of foreign cattle breeds as compared to DEC and IEC.

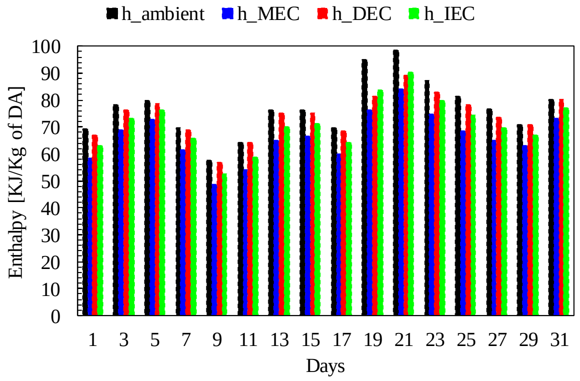

Fig. 10. Enthalpy comparisons of evaporative cooling system different ambient air conditions

Enthalpy of evaporative cooling systems can be compared at different ambient air conditions. Fig 10 represents the enthalpy comparison of evaporative cooling system. The enthalpy of direct evaporative cooling system remains same as compared to ambient conditions because in DEC system enthalpy of air remains constant by increase or decrease in temperature. The enthalpy of IEC system is greater than MEC

5. CONCLUSIONS

The effect of climate change and heat stress on livestock is highly neglected as compared to other application of agricultural production. The sternness of heat stress conditions in high-yielding dairy cows is currently underestimated. The present study investigates the system feasibility and evaluation of temperature-humidity index (THI) for foreign breeds of cattle under interior climatic zone in Multan**.** The results show the applicability of evaporative cooling system for foreign breeds of cattle. From the results it has been clear that the Maisotsenko evaporative cooling system is feasible for thermal comfort of livestock application in climatic condition of Multan and other warm and dry cities of Pakistan.

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Conflict of Interest

The authors declare no conflict of interest.

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