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A solar energy operated mechanism for mitigating heat stress in cattle barn

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Abstract
The heat stress felt by dairy cattle during summer months causes many negative consequences in terms of physiological and behavioral disturbances, susceptibility to diseases and a significant loss in milk production. To mitigate the heat stress, the microclimate of the barn should be known and based on which a suitable mechanism is to be adopted. In commercial dairying barns are often been erected with bricks wall and tin sheets roof and therefore this paper presents the level of heat stress faced by the dairy cattle in such type of barns and describes about a heat stress mitigation mechanism, operated by solar energy. The working pressure of the mechanism, ranged from 54-133 psi over the incident solar radiation intensity of 400-900 W/m^2. When, this pressured water is passed through nozzles of suitable aperture then very fine droplets of water are formed. This creates a fog like situation in the barn and associated evaporative mechanism reduces the barn temperature. The developed device covers even a good size barn and also covers many neighboring barns with appropriate networking mechanism. Though the experimental data is site specific but a close resemblance of climatic conditions of the experimental site and other parts of the country suggests a wider applicability of the mechanism.

Keywords: Heat stress, solar irradiance, cattle barn, working pressure, nozzles

Introduction
It is being strongly observed that the climate change has increased the intensity and duration of heat waves by trapping more heat in the atmosphere. This is leading to severe health impacts on humans and animals. The heat stress experienced by humans and animals is associated with air temperature in conjunction with humidity of the environment. The negative impacting is being felt in their production and reproduction, intensive selection of production traits, and evoke of physiological responses (Schüller *et al.*, 2014; Yasobant *et al.*, 2025, Habeeb *et al.*, 2018) [18, 20, 6]. It also negatively impacting the lactation phase and milk production in dairy cattle, as high productivity dairy cattle show a high amount of metabolic heat production and requires a cool surrounding for releasing excess heat (Wolfenson and Roth, 2019; Oliveira *et al*., 2025; Lambertz *et al*., 2014) [19, 14, 9].

The environmental risk factors on animals are assessed by an indicator, called Temperature-Humidity Index (THI). Some of the popular mathematical formulae for calculation of THI are reported in Table1. This indicator gives the effect of thermal stress in terms of ambient temperature and relative humidity (Bohmanova *et al.*, 2007) [3]. Based on experimental observations, the resilience of animals against the heat stress is classified by several researchers however the widely acceptable classifications of Hahn *et al.* (2009) [7] is enumerated in Table 2.

Based on these facts this paper describes the heat stress faced by dairy animals in the barns often erected with bricks walls and roof of tin sheets supported by iron angles. Such types of cattle barns are located at ICAR Research Complex for Eastern Region Patna (25.59°N, 85.08°E) and therefore selected for study and describes about a prototype solar energy operated mechanism for mitigating heat stress.

Table 1: Mathematical formulas for THI calculation

THI = 1.8T-(1-RH) (T-14.3) + 32	(Kibler, 1964) [8]
THI = (1.8 × T + 32)-(0.55-0.0055 × RH) × (1.8 × T-26)	(NRC, 1971) [12]
THI = T + (0.36 × Ta) + 41.2	(Yousef,1985) [21]
THI = (0.8 × T) + [(RH/100) × (T-14.4)] + 46.4	(Mader *et al*., 2006) [10]

T is the temperature (°C) and RH: relative air humidity (%) of animal environment

Table 2: The level of heat stress in dairy cattle

SL. No.	THI	Heat stress level
1.	< 74	Normal
2.	75-78	Alert
3.	79-83	Danger
4.	> 84	Emergency
5.	72	Critical threshold

Materials and Methods

The increasing trend of dairying at commercial level necessarily requires good infrastructure and high productivity dairy cattle. This has led to construction of sizeable barns often made of bricks walls, good number of windows fitted with wire mesh for proper ventilation, and iron angles supported painted tin sheets roof. The physical dimension of the barn selected for study was of 20 m × 7 m × 4 m. During intense heat waves conditions barn windows were covered with canvas cloths to avoid direct exposure of hot air. In the month of March to June, random measurements of temperature and relative humidity inside the barn showed that the absolute temperature difference between the barn temperature (T_b) and outdoor temperature (To), i.e., $\Delta T\ (= |T_b - T_0|)$ never exceeded 10 percent of the To, and similarly the absolute difference in relative humidity of barn (RH_b) and outdoor relative humidity (RH_0), i.e., $\Delta RH\ (= |RH_b - RH_0|)$ was always below 11%. The ΔT and ΔRH both were directly dependent on the wetness of barn, number of cattle in the barn and the wind flow through the windows. If windows were not covered then ΔT and ΔRH were minimum, as suggested in studies (Patil *et al*., 2025) [16]. With these observations, there were following possibilities:

T_0H_0	Temperature and humidity of barn were same as outdoor
$T_0H_\uparrow$	Temperature was same but the relative humidity was higher than the outdoor
$T_0H_\downarrow$	Temperature was same but the relative humidity was less than the outdoor
$T_\uparrow H_0$	Temperature was higher than the outdoor but humidity was same
$T_\uparrow H_\uparrow$	Temperature and humidity both were higher than the outdoor
$T_\uparrow H_\downarrow$	Temperature was higher than the outdoor, but relative humidity was lower
$T_\downarrow H_0$	Temperature was lower than the outdoor, but relative humidity was same
$T_\downarrow H_\uparrow$	Temperature was lower than outdoor, but relative humidity was higher
$T_\downarrow H_\downarrow$	Temperature and relative humidity both were lower than the outdoor

To outdoor temperature and relative humidity data were acquired from the nearby aerodrome weather station. The variation of maximum temperature and relative humidity of critical summer months of 2024 are shown in Fig. 1 and Fig. 2. Based on these data the thermal humidity indices were calculated by using NRC formula [THI= (1.8 × Tb + 32)-(0.55-0.0055 × RH_b)× (1.8 × Tb-26)]

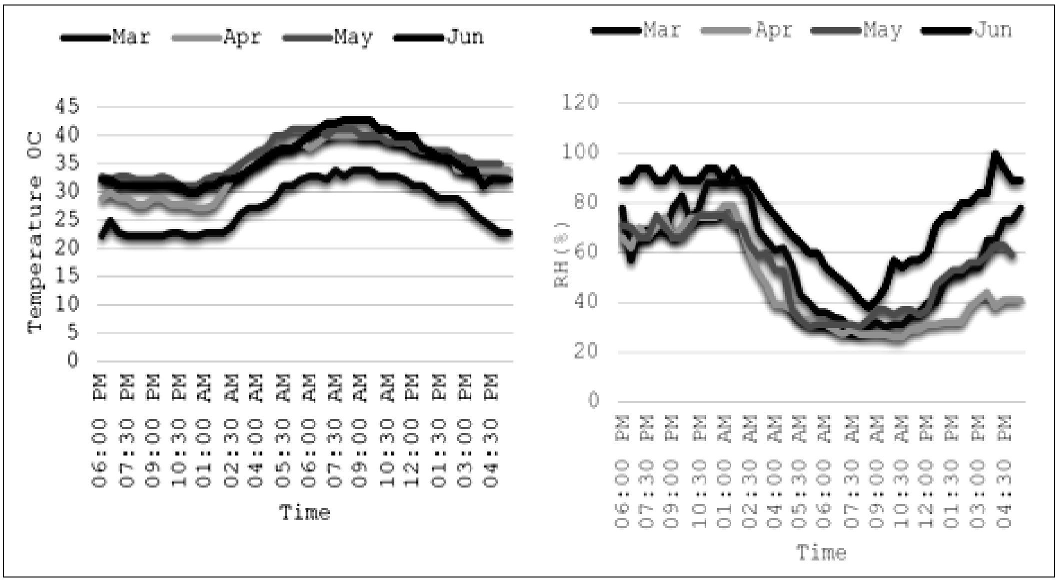

Fig 1: Outdoor maximum temperature and humidity over a day of critical summer months of the site

Results and Discussions

The THI of the barn at 8.00 am, 12.00 pm and 4.00 pm for critical summer month, of March-June is reported in Table 3. Interpretation of data shows that the heat stress level exceeded the permissible limits (> 74) almost in all the months throughout the day and therefore cattle were facing heat stress in all the months from March-June, and the degree of stress increased towards the June. This necessitated measures for the barn to assuage heat stress. As suggested in literatures (Bernabucci, 2019; Oke *et al*., 2021; Mohapatra *et al*., 2023; Anderson *et al*., 2013; Chen *et al*. 2015; Orellana Rivas *et al*., 2021; Broucek *et al*., 2020) [2, 13, 11, 1, 5, 15, 4] some common measures for heat stress mitigation include roof sprinkling, forced air supply, misting or fogging, but the selection of type of measures should be cost-effective and easy in maintenance. Further, to assess the changes in $\mathrm{THI(T,H)}$ of barn from reference vale $\mathrm{THI(T_0,H_0)}$ more elaborately under different scenarios, the $\Delta\mathrm{THI}$ was plotted for different month for different scenarios and is shown in Figure 2.

Table 4: THI of the barn under different scenarios during March to June

Time	T_0H_0	$T_0H_\uparrow$	$T_0H_\downarrow$	$T_\uparrow H_0$	$T_\uparrow H_\uparrow$	$T_\uparrow H_\downarrow$	$T_\downarrow H_0$	$T_\downarrow H_\uparrow$	$T_\downarrow H_\downarrow$
March									
8:00 AM	77.6	79.5	75.8	81.1	83.3	79.0	74.1	75.6	72.6
12:00 PM	74.3	75.4	73.1	77.9	79.3	76.5	70.6	71.5	69.7
4:00 PM	72.7	73.8	71.7	76.2	77.5	74.9	69.2	70.0	68.4
April									
8.00 AM	84.9	87.4	82.4	89.1	92.0	86.2	80.7	82.8	78.6
12:00 PM	83.4	85.7	81.1	87.5	90.2	84.8	79.3	81.2	77.4
4:00 PM	80.4	82.3	78.5	84.3	86.6	82.0	76.5	78.1	74.9
May									
8:00 AM	86.8	89.4	84.2	91.2	94.3	88.2	82.4	84.6	80.1
12:00 PM	84.7	87.0	82.4	89.0	91.7	86.3	80.4	82.3	78.4
4:00 PM	86.3	88.3	84.3	91.1	93.5	88.7	81.5	83.2	79.8
June									
8:00 AM	91.4	94.2	88.6	96.4	99.7	93.2	86.4	88.7	84.0
12:00 PM	92.5	95.0	90.0	97.9	100.8	95.0	87.1	89.2	85.0
4:00 PM	86.5	88.2	84.9	91.8	93.8	89.9	81.2	82.5	79.8

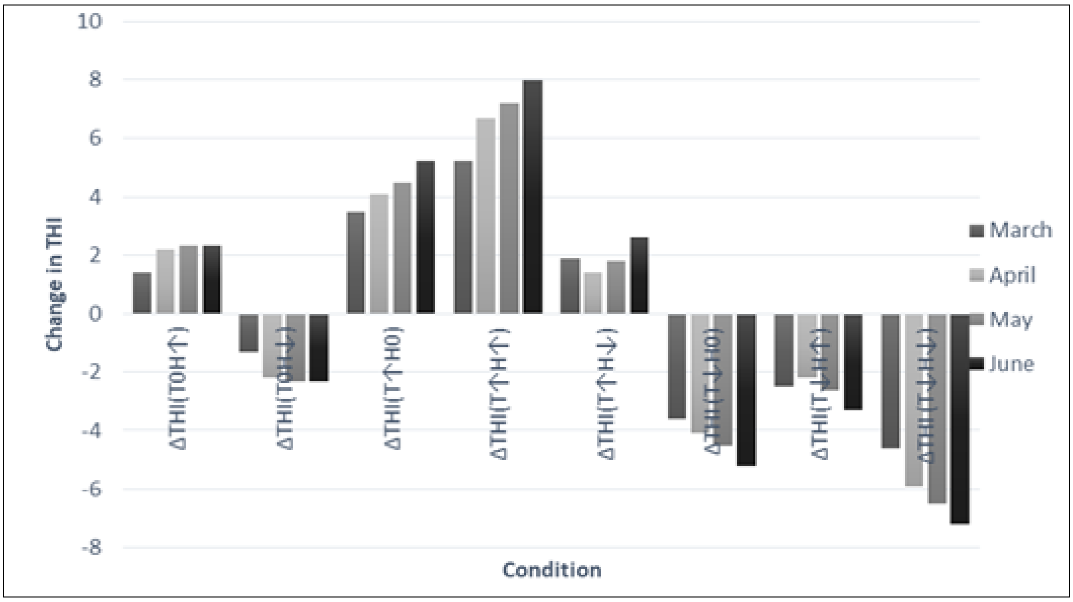

Fig 2: Change in heat stress level of barn under different scenarios from March to June

From Fig.2 it was observed that, under the scenarios $(T_0H_\uparrow)$, $(T_\uparrow H_0)$, $(T_\uparrow H_\uparrow)$ and $(T_\uparrow H_\downarrow)$, the changes $\Delta\mathrm{THI}_s$ were positive, however under the scenarios $(T_0H_\downarrow)$, $(T_\downarrow H_0)$, $(T_\downarrow H_\uparrow)$ and $(T_\downarrow H_\downarrow)$ the changes $\Delta\mathrm{THI}_s$ were negative. Therefore, the heat stress mitigation was possible only under the scenarios $(T_0H_\downarrow)$, $(T_\downarrow H_0)$, $(T_\downarrow H_\uparrow)$ and $(T_\downarrow H_\downarrow)$. A maximum $\Delta\mathrm{THI}$ was with $(T_\downarrow H_\downarrow)$, i.e., when temperature and humidity both were decreased simultaneously. This condition requires air conditioner, but it was a costly affair for a barn. The next maximum change was with the scenario $(T_\downarrow H_0)$ and this could be achieved by air blowing. But air blowing mechanism has a limitation that it has limited capacity of temperature reduction. The third maximum change was possible with the scenarios $(T_\downarrow H_\uparrow)$ and this can be achieved by misting or fogging.

Further a fogging mechanism needs continuous energy supply for operation. The required energy can be supplied either by electricity or by fossil fuel. Due to the lack of grid power connectivity and increase in fossil fuel cost and associated environmental factors, the solar energy application could be a better option. To assess the solar energy availability at experimental site the mean monthly averaged daily solar radiation of the site measured by pyranometer by Rahman and Bhatt (2014) [17] is shown in Figure 3. From Figure 3 it was observed that the solar irradiance was ranging from 200-953 W/m^2 over a day and the mean monthly daily averaged radiation intensity from March to June was 6.4-4.8 kW/m^2/day and could be good source of energy for operating heat stress mitigation mechanism in the cattle barn.

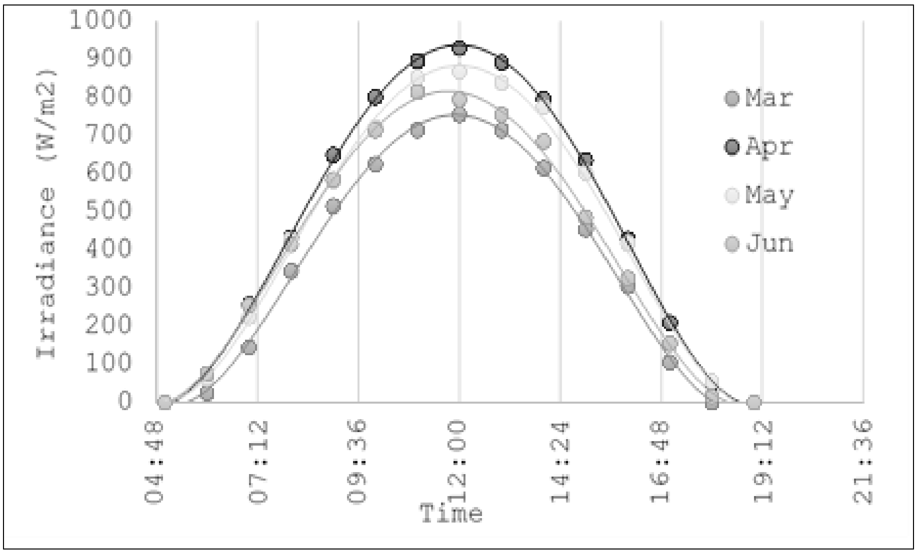

Fig 3: The mean monthly daily solar irradiance of the site

To utilize solar energy of the site a fogging mechanism was designed (Figure 4) using a permanent magnet DC motor of rating 1500 W, a 1.8 kWp photovoltaic solar array, a compressor of power dissipation rating of 1000 W, a plastic tank of 500 liters capacity, nozzles with adjustable aperture, ¾ inch GI pipe, high pressure flexible conduit and some control volves. The selection criteria of compressors were based on its working pressure and choosing nozzles with variable aperture was to get fine size water droplets even at low solar irradiance, as droplets size was inversely proportional to nozzle aperture.

Fig 4: The developed fogging mechanism

To assess the performance of the developed fogging mechanism under different solar radiation conditions, the working pressure of the mechanism was measured and plotted against the solar irradiance (Figure 5). The solar irradiance between 8.00 AM to 3.00 pm on a clear day of March to June was ranging from 400-900 W/m^2 and corresponding to this incident solar radiation range, the working pressure of the mechanism was 53-134 psi (Figure 5). For the selected barn *six* nozzles were networked using GI pipe from mechanism to barn and flexible pipe segments were used to connect the nozzles with GI line. These nozzles were installed at the windows of the barn (Figure 6). At relatively low pressure, the nozzle aperture was adjusted to reduce aperture area to get fine droplets.

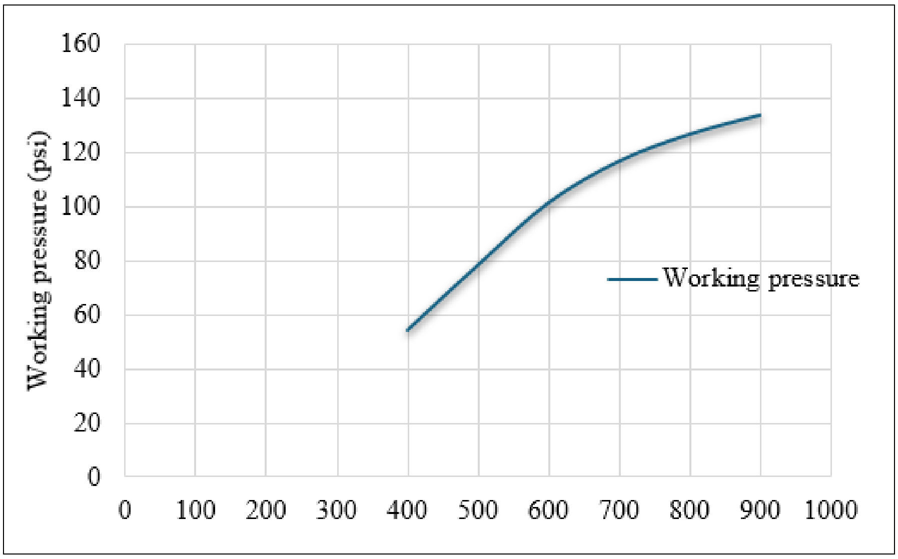

Fig 5: Working pressure of the mechanism vs. Solar irradiance of the site

Fig 6: Installation of nozzles in cattle barn

The operating view of the mechanism in the Bufalo barn is shown in Fig.7. There had been a substantial cooling once mechanism was operated for ½ hour. This mechanism cools the surfaces and air through the process of evaporative cooling where fine water droplets absorb heat from the surrounding air as they evaporate. Further, the tiny droplets remain suspended in the air a longer period and allowing evaporation for a longer period and lowers the temperature with increase in humidity. Further, a single mechanism can covered a large barn by operating only few nozzles at a time and can cover a number of nearby barns barns by diverting supply line other barns at a certain interval of time. The solar array operating the mechanism can also be used for groundwater pumping or lifting pond water from a nearby pond when fogging in barn was not required. Again, the outdoor conditions of temperature and humidity of the site is nearly similar to the temperature and humidity conditions as well as solar radiation conditions of other parts of the country, hence the developed mechanism has wider applicability.

Fig 7: Operatinal views of mechanism in Bufalo barn

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Conflict of interest
The author declares no conflict of interest

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