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Assessment of solar power-assisted cooling system for heat stress management in HF Deoni crossbred cows

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Abstract

A solar power-assisted system was developed and installed to create optimum, healthy environmental conditions inside the animal house. An improved animal house of 48 m^2 including a manger and urine collection system was selected. The developed system consists of two solar panels of 37 watts each with a DC motor coupled with a pump, four-way foggers, battery (12 V, 22 Ah), charge controller, digital timer, pressure gauge, and water tank (200 L). The assessment of the developed cooling system was carried out by measuring AT (air temperature), RH (relative humidity), THI (temperature–humidity index), and RT (rectal temperature) using 6, 12, and 18 foggers at three different heights of 2.25, 2.5, and 2.75 m with 2, 4, and 6 min operational time intervals. The AT, RH and THI were strongly influenced by the fogger cooling system, wherein AT was lowered by 9.2–2.6 °C and RH was increased from 13–47% inside the animal house. The minimum rectal temperature of 38.11 °C and THI 81.71% was recorded at 18 foggers installed at a height of 2.75 m with a 4 min operational time interval. Therefore, the installed solar power-assisted cooling system for fogging water created an optimum cooling effect inside the animal house.

Keywords: cooling effect, digital timer, heat stress, relative humidity and temperature–humidity index

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Introduction

The production of milk in cattle and buffalo is well recognised and they contribute approximately 96% of the total milk production in India. Even though India's milk output increased by 3.5% in 2012–2013 to reach 132.4 million tonnes, there is still a strong demand for milk (BAHS, 2014) and according to projections, India would be able to produce 200 million tonnes of milk by 2030 (Dash *et al.,* 2016). This target will be achieved if there is an optimum balance between productivity and fertility.

Dairy animals have a physiological body temperature of 38.4–39.1 °C and a relative humidity ranging from 60–80% in their thermoneutral zone, which is 16–25 °C (Yousef, 1985; West, 2003). India is a tropical country with hot and humid summers and a relatively less-stressful winter season. During summer, the atmospheric temperature reaches as high as 40–45 °C. During these hot and humid summer conditions, the atmospheric conditions exceed a threshold limit, which enhances heat gain beyond that lost from the body and this induces heat stress in animals (Sunil *et al*., 2011). As a

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result, body surface temperature and rectal temperature (RT) increase, which in turn affects animal health, feed intake, production, and reproductive efficiency.

There are a number of methods for physically altering the barn environment to lessen the negative impacts of high ambient temperatures and heat stress, such as a well-insulated barn roof and effective natural ventilation control. One of the simplest and most affordable ways to reduce heat from sun radiation is by using shading, either natural or artificial. With a well-designed shade, it has been predicted that the overall heat load in outdoor spaces can be decreased by 30% or more (Blackshaw & Blackshaw, 1994). Although shade reduces heat build-up from solar radiation, it has little effect on air temperature or relative humidity; therefore, dairy cows in hot humid climates require supplementary cooling.

A number of cooling options exist for dairy sheds based on combinations of the principles of convection, conduction, radiation, and evaporation, *viz*., air conditioning, zone cooling, evaporative cooling pads, and direct wetting of the animal with water using sprinklers followed by strong forced ventilation, foggers, and misters. Foggers and misters, two examples of evaporative cooling devices, employ the energy in the air to evaporate water. High-pressure fogging systems use numerous fog nozzles to disseminate very fine water droplets into the air. Fogging systems produce smaller (15 and 50 µm) diameter droplets than misting systems. As fog droplets are emitted, they immediately spread into the air, where they soon evaporate. Animals are chilled as cool air is blown over their bodies and as they inspire cooled air, the evaporation of water into warm air reduces the air temperature while increasing relative humidity (Renaudeau *et al.,* 2012). This study was undertaken with the objective of the development and assessment of a solar power-assisted cooling system to manage heat stress in crossbred cows.

Materials and Methods

The experiment was approved by the animal ethics committee of the University of Agricultural Sciences, Raichur, Karnataka, India (UASR/01/2022).The study was conducted at the dairy unit, Main Agriculture Research Station, University of Agricultural Sciences, Raichur. It lies at 16.2012° N and 77.3245° E. The climate of the Raichur district is characterised by dryness for the major part of the year and a very hot summer. The summer season starts in March and extends until May. April and May are the hottest months. During these two months, the weather becomes very dry and uncomfortable, and the temperature may reach up to 42 °C.

The solar power-assisted cooling system was developed by considering the area of the animal housing structure and meteorological parameters. In the current investigation, the type of housing system was a face-out system, in which the cows were housed, fed, and milked during the experiment. The cows inside the barn were arranged in two rows of four animals each. The total floor area selected was 48 m^2 (length of 9.2 m and width of 5.22 m). The manger was 1.1 m wide with front and back heights of 70 and 60 cm, respectively. The study area was isolated from the other half of the house by covering it with an HDPE green shade net with a 50% opening (Fig. 1).

The metrological parameters, *viz*., air temperature and relative humidity, were recorded during the entire period of the study under the natural and solar power-assisted cooling system and the temperature–humidity index (THI) was also calculated. The daily average values of air temperature, relative humidity, and THI outside the experimental house are presented in Table 7, Figs 5, 6, and 7, respectively. The minimum and maximum outside air temperature during the experimental period was 36.4 °C and 41.0 °C, respectively (Table 1). The minimum and maximum outside RH recorded during the experimental period was 17% and 33%, respectively. The maximum outside THI was 83.90 and a minimum of 82.50 was observed during the experimental period.

The solar power-assisted cooling system was developed and installed in the face-out dairy house selected for the study. The cooling system consists of a maximum of 18 foggers, each of which had a discharge rate of 12 $L.h^{-1}$ (Table 2). The solar power-assisted cooling system was equipped with a direct current (DC) pump coupled to a motor of 84 W (12 V, 7 A) and an operating pressure of 4.1 $kg.cm^{-2}$. The system was provided with two solar panels of 37 W each. The cooling system comprises a digital timer, a 22-meter LLDPE lateral, and a 250-L water tank (flow chart of the cooling system, Fig. 2). A pump capacity of 84 W (12 V & 7 A) with 4.1 $kg.cm^{-2}$ operating pressure and discharge rate of 4.1 $L.min^{-1}$ was selected on the basis of the maximum discharge rate and operating pressure of the cooling system and it was found that the maximum discharge of the cooling system was 3.2 $L.min^{-1}$ at 4.1 $kg.cm^{-2}$.

Table 1 Measured daily average outside air temperature, relative humidity, and temperature-humidity index during the experimental period (April–May 2022)

Period	Air temperature (ºC)	Relative humidity (%)	Temperature–humidity index
Day 1	36.6	30	82.50
Day 2	36.4	33	82.80
Day 3	36.9	31	82.90
Day 4	37.0	31	83.00
Day 5	37.8	28	83.20
Day 6	37.0	32	83.20
Day 7	37.0	31	83.00
Day 8	38.2	27	83.40
Day 9	38.8	24	83.30
Day 10	39.0	24	83.50
Day 11	38.4	26	83.40
Day 12	36.9	31	82.90
Day 13	37.2	34	83.90
Day 14	37.8	28	83.20
Day 15	39.8	21	83.60
Day 16	38.7	23	82.90
Day 17	40.0	19	83.30
Day 18	40.0	19	83.20
Day 19	40.2	17	82.90
Day 20	40.9	18	83.90
Day 21	41.0	17	83.70
Day 22	39.8	20	83.30
Day 23	40.7	17	83.40
Day 24	37.7	28	83.10
Day 25	39.0	22	83.00
Day 26	39.8	19	83.20
Day 27	40.0	19	83.30

Figure 1. Solar power-assisted cooling system in an animal housing structure

Table 2. Specifications of foggers used for discharging water

Sl. No.	Particulars	Specification
1	Brand	Netafim
2	Model	Coolpro net 055
3	Colour	Light Green
4	Material type	Plastic
5	Operating pressure	4.0-5.0 Bar
6	Droplet size	65 Micron
7	Flow rate	12 l h^{-1}

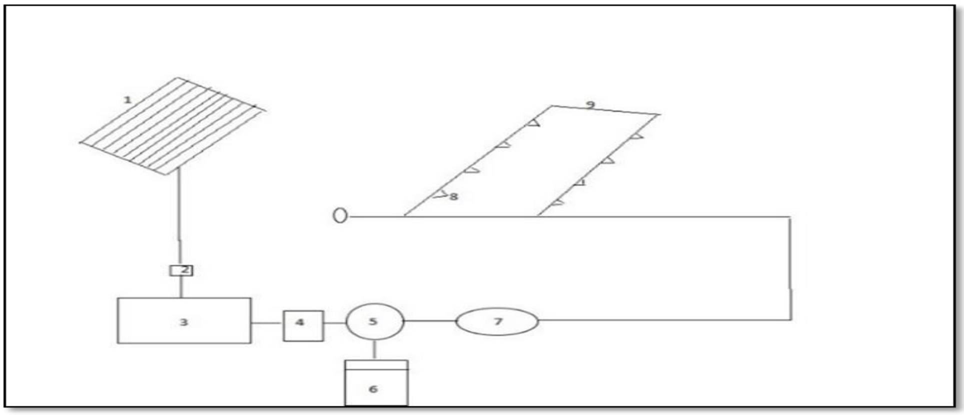

Figure 2. Schematic diagram of the cooling system

1. Solar panel
2. Charge controller
3. Battery
4. Timer switch
5. DC motor coupled with pump
6. Water tank
7. Pressure gauge
8. Fogger assembly
9. Pipe
10.

The panel capacity was decided based on the power requirement by the selected pump. The maximum power required the pump to discharge the desired flow rate at maximum operating pressure was found to be 60 W. Thus, two solar panels of 37 W each were selected and installed on the roof of the animal house supported with mild steel square bars (Table 3. specification of solar panel).

Table 3. Specifications of selected solar panel

Sl. No.	Particulars	Specification
1	Panel capacity	37 W
2	Irradiance	1000 W m^{-2}
3	Ambient temperatu	27.2°C
4	Voltage	12 V
5	Current	2.08 A
6	Model efficiency	15.3 per cent

The system was provided with 12 V & 22 Ah lead acid, dry type battery and a solar charge controller. When completely charged, the selected battery had a backup capacity of up to 6 h. Additionally, a provision was made to charge the battery using grid electricity to handle cloudy days when the sunshine was insufficient to generate the necessary power to run the cooling system. The pump was mounted to the rigid H beam with the help of a binding wire. The battery, timer, charge controller, and pump were mounted to the H beam under the roof in series. A frame made of mild steel bars, which was supported by two mild steel angle bars, held the battery in place by connecting it to the H beam. The digital timer and charge controller were fitted to a wooden panel that was mounted to a rigid H beam of the housing structure using bending wire. The PVC water tank was set on a platform of a six foot water tank stand, which was constructed of mild steel angle bars. A 6 m × 3 m rectangular frame composed of square stainless-steel bars was used as support to place the lateral pipe within the house. The lateral pipe was fitted with the foggers, which were equidistantly spaced.

The major objective of the study was to develop a solar power-assisted cooling system and assess its ability to manage heat stress in cows. The effect on dependent variables, *viz., a)* air temperature, b) RH, c) THI, and d) rectal temperature by varying selected independent variables *viz.,* a) height of the fogger, b) number of foggers, and c) operational time interval were assessed (Table 4). The assessment was carried out in the animal house from April to May (2022) for a period of 60 d, with optimum system operational parameters. For this study, eight HF Deoni crossbred dairy cows were selected based on age, body weight, and stage of lactation. At the start of the experiment, cows were approximately 7 years and weighed 350–400 kg.

Table 4. Selected variables for the experiment

Sl. No.	Variables	Levels
	Independent variables	
a.	Number of foggers	3 (6, 12, and 18)
b.	Height of the fogger (m)	3 (2.25, 2.50 and 2.75 m)
c.	Operational time interval (min)	3 (2, 4 and 6 min)
	Dependent variables	
a.	Air temperature (°C)	-
b.	Relative humidity (%)	-
c.	Temperature-humidity index	
d.	Rectal temperature (°C)	

Measurement of variables

a) Air temperature: The air temperature in the animal house during the experiment was recorded by using a dry bulb thermometer (Sandeep, 2014). The dry bulb thermometer was placed at the central part of the house and the average reading was recorded.
b) Relative humidity: The RH was calculated from dry bulb and wet bulb temperatures by using the psychrometric chart of the Indian Meteorological Department (Sandeep, 2014). The environmental variables were recorded three times a day at 02:00, 03:30, and 17:00.
c) Temperature-humidity index: THI is a single value representing the combined effects of air temperature and humidity associated with the level of thermal stress. A THI of ≤74 is considered to be normal, 75–78 is indicator of alert status, 79–83 is considered to be dangerous, and a THI ≥84 is an emergency condition for cows (Habeeb *et al.,* 2018). The temperature humidity index was calculated using the following formula (Thom, 1959):

$$\mathrm{THI} = (0.8 \times T) + RH(T - 14.4) + 46.4 \quad (1)$$

where T = Air temperature (°C); RH = Relative humidity (decimal)

d) Rectal temperature (RT): The RT was recorded accurately by a clinical digital thermometer inserted ~3-cm deep into the rectum, ensuring that the thermometer bulb was left in contact with the rectal mucosa for 1.5–2.0 min. The measurement was terminated when an acoustic signal was emitted by the digital thermometer and the probe was retracted from the rectum (Ferdinando *et al.,* 2012).

The parameters under study were analysed using a completely randomised factorial design. An analysis of variance (ANOVA) was used to analyse the experimental data to evaluate the impact of three independent variables. The statistical software package "Design–Expert" (version 10.04 for Windows, Stat-Ease, Inc.,) was used for statistical analysis.

Results and Discussion

The functional components required for the cooling system were procured and the development work of the system was carried out at the Department of Farm Machinery and Power Engineering, College of Agricultural Engineering, UAS Raichur. The developed solar power-assisted cooling system was installed in an experimental animal housing structure at a dairy unit selected for the study and its effectiveness for animal comfort was assessed. Parameters such as air temperature, RH, THI, and RT were recorded during the experiment.

The air temperature inside the experimental animal house decreased and RH increased with an increase in the number of foggers (6, 12, and 18) installed at heights of 2.25, 2.50, and 2.75 m with operational time intervals of 2, 4, and 6 min. A minimum of 2.6 °C (34 °C inside vs 36.6 °C outside temperature) and a maximum air temperature reduction of 9.2 °C (30.6 °C inside vs 39.8 °C outside AT) were recorded and a minimum of 13% (43% inside vs 30% outside RH), and maximum relative humidity increase of 47% (66% inside vs 19% outside RH) were observed at a treatment combinations of [6 foggers–2.25 m height–2 min operational time interval] and [18 foggers–2.75 m height–4 min operational time], respectively, when compared to outside AT and RH. This is because, as the number of foggers increased from 6 to 18 for a total floor area of 48 m^2, the number of foggers per unit floor area also increased, i.e., one fogger covered an 8-m^2 floor area with 6 foggers and one fogger covered 4-m^2 and 2.7-m^2 floor area with 12 and 18 foggers, respectively. Due to the increase in the number of foggers, moisture addition in the air by the cooling system lowered the air temperature inside the animal housing structure (Angelika *et al.,* 2007; Titto *et al.,* 2013; Botto *et al.,* 2014; Sinha *et al.,* 2019).

In the case of the height of fogger and operational time interval, the AT decreased with increasing vertical height of the fogger from the ground and operational time interval. This is due to the increase in the height of the fogger and time interval; the moisture addition by the cooling system increased and more climate was cooled down inside the house (Fig. 3, 4, 5). RH increased (Fig. 5, 6, 7) within the house as a result of the drop in air temperature (Chaiyabutr *et al.,* 2008; Titto *et al.,* 2013; Ajaykumar, 2018).

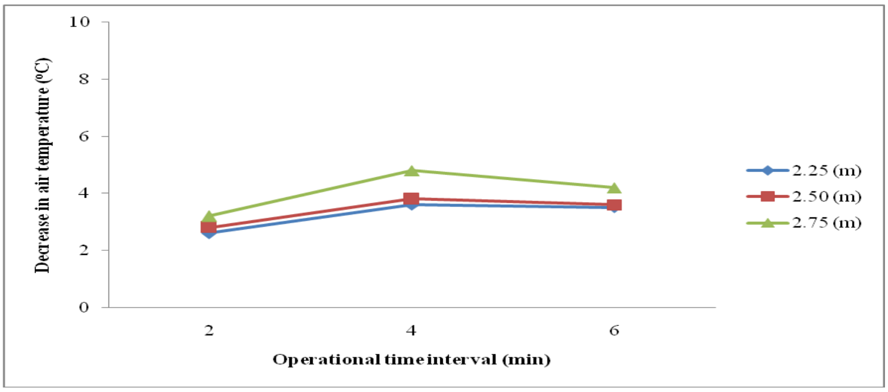

Figure 3. Effect of operational time intervals and different heights of foggers on air temperature with foggers

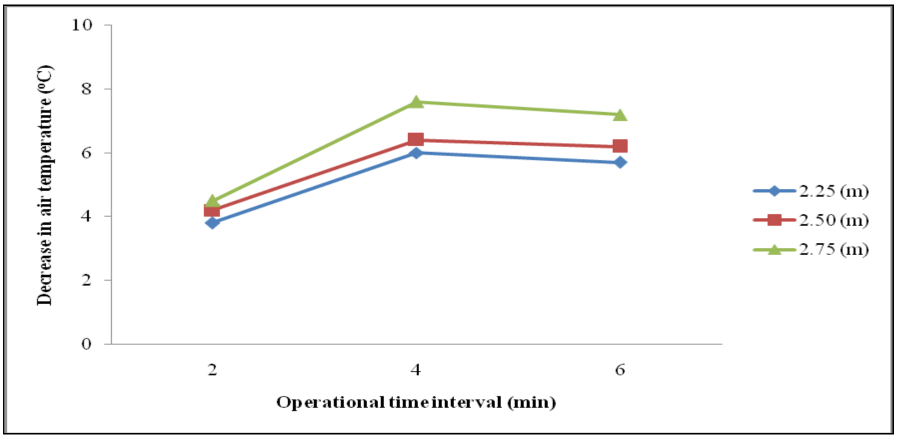

Figure 4. Effect of operational time intervals and different heights of foggers on air temperature with 12 foggers

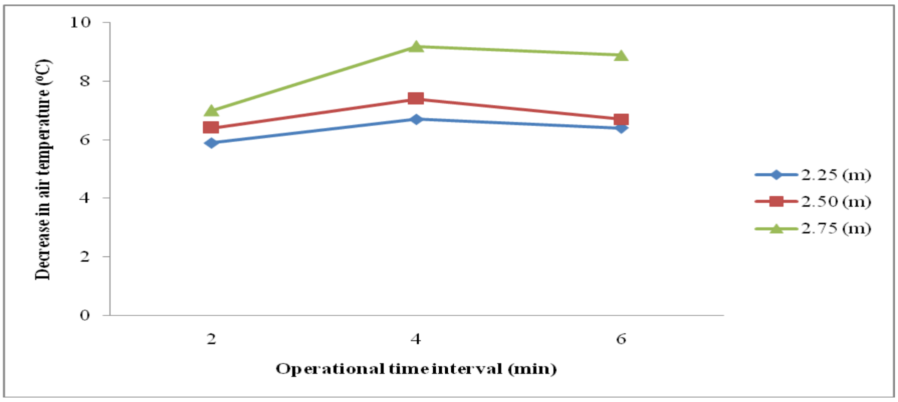

Figure 5. Effect of operational time intervals and different heights of fogger on air temperature with 18 foggers

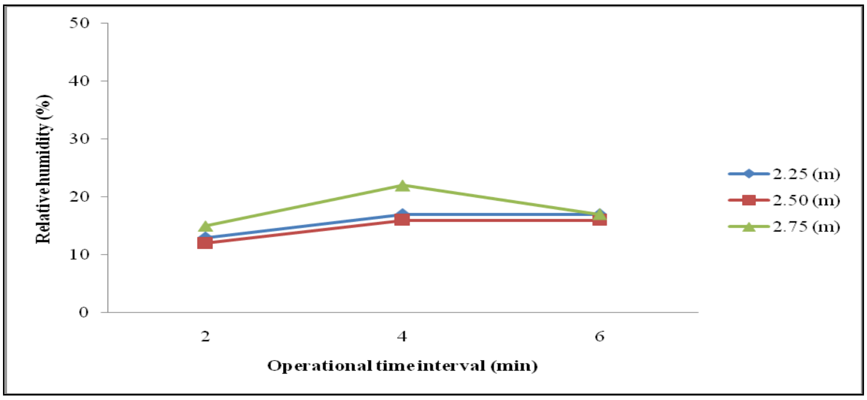

Figure 5. Effect of operational time intervals and different heights of fogger on relative humidity with six foggers

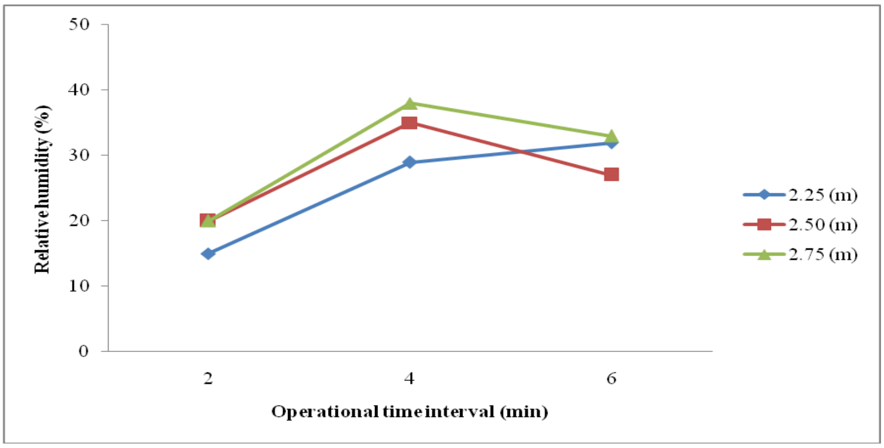

Figure 6. Effect of operational time intervals and different heights of fogger on relative humidity with 12 foggers

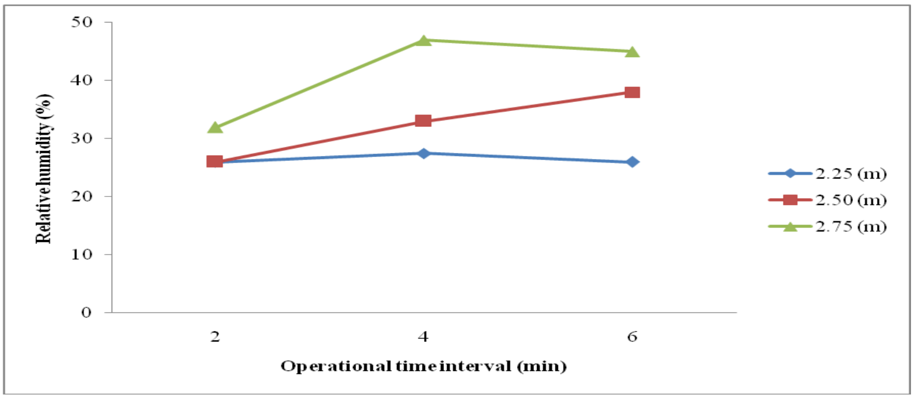

Figure 7. Effect of operational time intervals and different heights of fogger on relative humidity with 18 foggers

When compared to outside THI, a considerable drop in THI was seen within the experimental house (Table 5).

Table 5. The effect of the cooling system on temperature–humidity index

Period	Treatment Combinations (Number, Height of fogger & time)	Inside THI	Outside THI	Decrease in THI
Day 1	6-2.25-2	82.20	82.50	0.3
Day 2	6-2.25-4	81.79	82.80	1.0
Day 3	6-2.25-6	82.22	82.90	0.7
Day 4	6-2.50-2	82.19	83.00	0.8
Day 5	6.2.50-4	82.17	83.20	1.0
Day 6	6-2.50-6	82.22	83.20	1.0
Day 7	6-2.75-2	82.29	83.00	0.7
Day 8	6-2.75-4	82.50	83.40	0.9
Day 9	6-2.75-6	82.41	83.30	0.9
Day 10	12-2.25-2	82.72	83.50	0.8
Day 11	12-2.25-4	82.17	83.40	1.2
Day 12	12-2.25-6	81.49	82.90	1.4
Day 13	12-2.50-2	82.90	83.90	1.0
Day 14	12-2.50-4	82.17	83.20	1.0
Day 15	12-2.50-6	82.56	83.60	1.0
Day 16	12-2.75-2	82.03	82.90	0.9
Day 17	12-2.75-4	82.48	83.30	0.8
Day 18	12-2.75-6	82.10	83.20	1.1
Day 19	18-2.25-2	82.20	82.90	0.7
Day 20	18-2.25-4	82.54	83.90	1.4
Day 21	18-2.25-6	82.68	83.70	1.0
Day 22	18-2.50-2	81.92	83.30	1.4
Day 23	18-2.50-4	82.43	83.40	1.0
Day 24	18-2.50-6	81.91	83.10	1.2
Day 25	18-2.75-2	81.53	83.00	1.5
Day 26	18-2.75-4	81.70	83.20	1.5
Day 27	18-2.75-6	81.94	83.30	1.4

When the cooling system was installed with six foggers, a minimum THI drop of 0.3 (inside THI 82.20 vs outside THI 82.50) and maximum THI drop of 0.9 (inside 82.50 vs outside 83.40) were recorded at treatment combinations of 6 foggers–2.25 m height–2 min interval and 6 foggers–2.75 m height–4 min interval, respectively. When the system was operated with 12 foggers, minimum (0.8) and maximum (1.4) drops in THI were observed at treatment combinations of 6 foggers–2.25 m height–2 min interval and 6 foggers–2.75 m height–4 min interval, respectively. It was also evident that for the cooling system installed with 18 foggers, a maximum THI drop of 1.5 (81.71 vs 83.20) was recorded at the treatment combination of 18 foggers–2.75 m height–4 min interval and a minimum THI drop of 0.7 was recorded at 18 foggers–2.25 m height–2 min interval, respectively.

The THI decreased with an increase in the number of foggers. This is because the increase in the number of foggers added more moisture to the environment inside the house, thereby reducing the air temperature and increasing the relative humidity. Thus, the cooling system lowered the THI inside the animal house. In the case of the height of the fogger, THI inside the house decreased substantially with an increase in the vertical height of the fogger from the ground. This decrease is due to an increase in the height of the fogger, as more of the climate cooled inside the animal housing structure and less wetting of the floor was also observed. In the case of operational time interval, THI decreased with an increase in the operational time interval. Therefore, the moisture addition by the cooling system increased and a greater cooling effect was observed. However, the cooling impact was more pronounced at the 4-min than at the 6-min interval. This is because, during the 6-min interval off period, there was a slight increase in air temperature and a decline in relative humidity. The results obtained are similar to the findings of Das *et al*. (2014) and Sinha *et al.* (2019).

The analysis of the overall model was significant with an R^2 value of 0.7571 (Table 6). Significance was observed in the order of the number of foggers, followed by the height of fogger and operational time interval. The standard deviation and coefficient of variation were found to be 0.32 and 0.39%, respectively, with a mean value of 82.14.

Table 6. Analysis of variance for the temperature–humidity index

Source	Sum of Squares	DF	Mean Square	F Value	P-value
Model	16.97	26	0.65	6.47	< 0.0001**
A-Number of foggers	1.94	2	0.97	9.63	0.0003**
B-Height of the fogger	2.94	2	1.47	14.56	< 0.0001**
C-Operational time interval	1.42	2	0.71	7.02	0.0019**
AB	2.31	4	0.58	5.73	0.0006**
AC	1.94	4	0.48	4.80	0.0022*
BC	1.17	4	0.29	2.90	0.0300*
ABC	5.26	8	0.66	6.52	< 0.0001**
Pure Error	5.44	54	0.10		
Cor Total	22.41	80			
Std. Dev. = 0.32 Mean = 82.14 C.V. % = 0.39			R^2 = 0.7571 ** = Significant at 0.01 -		

There was a substantial decrease in the rectal temperature (RT) of cows in the treatment group inside the experimental house when compared to the RT of the same animals at the beginning of the experiment. An average RT of 39.86 °C was recorded at the beginning of the experiment. A minimum RT of 39.27 and 39.40 °C at treatment combinations of 6 foggers–2.75 m height–4 min interval and 6 foggers–2.25 m height–2 min interval, respectively (Table 7).

Table 7. Effect of number of foggers, height of the fogger, and operational time interval on rectal temperature

Sl no.	Number of foggers	Height of the fogger (m)	Rectal temperature (°C) Operational time interval (min)		
			2 min	4 min	6 min
1	6	2.25	39.40	39.25	39.21
		2.50	39.39	39.38	39.29
		2.75	39.30	39.27	39.38
2	12	2.25	38.94	38.50	38.39
		2.50	38.67	38.36	38.61
		2.75	38.63	38.33	38.44
3	18	2.25	38.93	38.55	38.61
		2.50	38.83	38.50	38.11
		2.75	38.61	38.11	38.22

When the system was operated with 12 foggers, a minimum RT reduction of 0.92 °C (*i.e.,* RT of cows under treatment group 38.94 °C vs 39.86 °C RT of cows at the beginning) and a maximum of 1.53 °C (*i.e.,* RT of 38.33 °C for cows under the treatment group vs 39.86 °C RT of cows at the beginning) reduction in RT was observed at the treatment combination of 12 foggers–2.25 m height–2 min interval and 12 foggers–2.75 m height–4 min interval, respectively.

It was also evident that the cooling system installed with 18 foggers produced a minimum reduction in RT 0.93 °C (*i.e.,* RT of 38.93 ºC for cows in the treatment group vs 39.86 °C RT of cows at the beginning of the experiment) and a maximum of 1.75 °C (*i.e.,* RT of cows in the treatment group 38.11 °C vs 39.86 °C RT of cows at the beginning) at treatment combination of 18 foggers–2.25

m height–2 min interval and 18 foggers–2.75 m height–4 min interval, respectively. Thus, a reduction in RT was observed with an increase in the number of foggers per unit floor area, where each fogger occupied 8, 4, & 2.7 m^2 floor area with 6, 12, & 18 foggers, respectively. The addition of more moisture at 18 foggers automatically reduced the air temperature and increased the relative humidity. Thus, the cooling system lowered the RT of cows inside the animal housing structure by creating more comfortable climatic conditions for the cows.

The RT inside the house decreased substantially with an increase in the vertical height of the fogger from the ground. This decrease was caused by the fact that when fogger height increased, the indoor climate cooled down more and the floor was not as wet at higher elevations. However, compared to the 2.75-m fogger height, there was little cooling difference between 2.25-m and 2.5-m fogger heights.

A substantial decrease in RT was to an increase in the operational cyclic time interval; the moisture addition by the cooling system reduced AT and THI and increased the RH. Thus, more cooling created a comfortable climatic condition inside the animal house. However, compared to the 6-min period, the cooling effect was more noticeable at the 4-min interval. This was due to the slight rise in AT and a drop in RH during the 6-min interval off phase. Thus, more comfort of the animals was observed at a 4-min interval. These results are in agreement with those of Singh *et al.* (2014) and Ghosh *et al.* (2018).

The number of foggers, height of the fogger, and operational time interval substantially influenced RT (Table 8). Significance was observed in order the of number of foggers, followed by the height of fogger, and operational time interval. The model was significant with an R^2 value of 0.9695. The standard deviation and coefficient of variation were 0.088 and 0.23%, respectively, with a mean value of 38.64 °C.

Table 8. Analysis of variance for rectal temperature (RT)

Source	Sum of Squares	DF	Mean Square	F Value	P-value
Model	13.33	26	0.51	65.91	< 0.0001**
A-Number of foggers	11.38	2	5.69	731.29	< 0.0001**
B-Height of the fogger	0.14	2	0.068	8.71	0.0005**
C-Operational time interval	0.94	2	0.47	60.14	< 0.0001**
AB	0.098	4	0.024	3.14	0.0214*
AC	0.50	4	0.12	16.00	< 0.0001**
BC	0.038	4	0.03	1.21	0.3155
ABC	0.25	8	0.031	4.00	0.0009*
Pure Error	0.42	54	0.034		
Cor Total	13.75	80			

Std. Dev. = 0.088	R^2 = 0.9695
Mean = 38.64	* = Significant at 5%
C.V. % = 0.23	** = Significant at 1%

For a floor area of 48 m^2, the optimum number of foggers was 18, meaning that each fogger covered ~2.7 m^2 and creates more favourable environmental conditions to manage heat stress when operated at a height of 2.75 m with a 4-min spray period. To further evaluate the impact of the cooling system, the system can be changed for use in research by varying the on/off time interval under modified roof structures of animal houses.

Conclusion

The result of the present investigation indicates that the maximum drop in indoor air temperature of 9.2 °C (30.6 °C) and maximum RH of 66% was achieved with optimum system operational parameters of 18 foggers, installed at 2.75 m height, and a 4-min operational time interval. Under these optimized conditions, a minimum RT of 38.11°C (with a reduction of 1.75 °C) and THI of 83.20 (reduction of 1.5) were recorded. Thus, the cooling system managed the heat stress in cows by creating optimum environmental conditions.

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