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RESEARCH ARTICLE

Effect of roof modifications on micro-climate in loose housing system of lactating Murrah buffaloes

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Abstract: The purpose of this study was to assess how well roof modifications more especially, false ceilings composed of glass wool and expanded polyethylene (EPE) sheets painted with reflective white paint—could reduce heat stress and enhance the microclimate in the loose housing system of lactating Murrah buffaloes in subtropical climates. The experiment was conducted at the Buffalo Farm, LUVAS, Hisar, India, for ninety days. An asbestos roof without any modifications (T1, control), an asbestos roof with a glass wool false ceiling and white paint (T2), and an asbestos roof with an EPE sheet false ceiling and white paint (T3) were the three treatments that were compared. The temperature of the internal shed, relative humidity (RH), upper roof temperature (URT), false ceiling temperature (FCT), and floor temperature (FT) were recorded on a fortnightly basis for 3 consecutive days, along with macroclimatic parameters. The findings indicated that T2 group had the best thermal insulation and heat reflectance, maintaining significantly ($P<0.05$) the lowest interior, upper roof, false ceiling, and floor temperatures with the most stable relative humidity. T1 displayed the highest temperatures and the most heat stress, whereas T3 performed in the middle. T2 considerably moderated thermal load by achieving a temperature reduction of 4–7°C in comparison to the macroclimate. According to the research, dairy buffaloes' thermal comfort is significantly increased by integrated roof insulation and reflective surfaces, which improves their welfare and productivity in hot climates.

Keywords Buffalo, Heat stress, Insulation, Microclimate, Roofing

Introduction

The buffalo is considered a multipurpose livestock species in the Indian subcontinent, valued for its meat, milk, and draft power (Pasha & Hayat, 2012). The world's most productive buffalo breed is the Murrah, sometimes known as the "Black Gold" (Kumar et al. 2019). Native to the districts of Bhiwani, Hisar, Rohtak, Jind, Jhajjar, Fatehabad, and Gurgaon in Haryana, Murrah buffaloes have been widely graded, dispersed, and exported to China, Brazil, Egypt, Bulgaria, and Bangladesh in order to improve local buffalo genetics (Dhilod et al. 2018). The high ambient temperatures in tropical and subtropical regions animal productivity is primarily limited by temperature, and the effects of heat stress become more severe when high humidity is present (Amit et al. 2021). The necessary adaptation measures must be implemented in order to mitigate the impact of increasing heat stress on cattle production. Examples of adaptations include adding cooling, ventilation, and shade systems, as well as switching to more heat-tolerant breeds. (Thornton et al. 2022). The implementation of water cooling systems, providing shade, and improving feed supplementation are promising methods that have demonstrated promise in reducing thermal stress and increasing livestock productivity (Slayi & Jaja 2025). The roof of the shed is essential for preserving the inside microclimate since it blocks direct sunlight, which can contribute up to 340 kcal/m² per hour (Sastry & Thomos, 2012). Roof design as a successful heat mitigation technique has been the subject of numerous research projects. In contrast to ambient conditions, Kamal et al. (2016) showed that asbestos roofs with canvas layers, agro-net, and thatch polythene shade considerably reduced interior temperatures. Similarly, adding reflective paints to the roof surface improves solar reflectance; according to Sastry and Thomos (2012), white, green, and aluminium paints reflect 75%, 50%, and 45% of solar radiation, respectively. Buffalo sheds are increasingly using innovative techniques like insulated false ceilings. Glass wool and expanded polyethylene (EPE) sheets are popular materials because of their superior thermal insulation qualities. Three layers

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of glass wool reduced interior temperatures by 1.5°C, according to Muhieldeen et al. (2020). EPE sheets under asbestos lowered maximum shed temperatures by 1.5°C and false ceilings can also reduce the temperature of the floor and roof according to Narwaria (2020).

The purpose of this study was to provide useful, affordable solutions for enhancing animal welfare and productivity by conducting a scientific evaluation of the effects of false ceilings made of glass wool and EPE sheets combined with white-painted roofs on microclimate parameters, including temperature, RH, THI, upper roof temperature (URT), false ceiling temperature (FCT), and floor temperature (FT), in the loose housing of lactating Murrah buffaloes.

Materials and Methods

The current research was carried out at the Buffalo farm of the Department of Livestock Production Management, College of Veterinary Sciences, Lala Lajpat Rai University of Veterinary and Animal Sciences, Hisar. The experiment was conducted in 2024 between August and October. Hisar district experiences exceptionally hot summers due to its continental climate. During the summer, the highest recorded temperature can occasionally surpass 45 degrees Celsius. The range of relative humidity is 5 to 100%.

Buffalo shed with asbestos roofing was taken to modify the microclimate inside the animal shed. Three treatments/ modifications were done as follows:

T_1 (Control):- Corrugated asbestos sheets roofing.

T_2:- Glass wool (50 mm) as false ceiling and white paint on upper roof.

T_3:- Expanded polyethylene sheet (70 mm) on false ceiling and white paint on upper roof.

Both the open space and the floor under the covered portion had cement pavers. The shed's walls were plastered on the inside. Each treatment involved a separate modification to the corrugated asbestos sheet roof, which was 2.5 to 3 meters high. The 1.25-meter-tall wall surrounded the shed's open space.

Metrological data

Meteorological data (macroclimatic and microclimatic) for each treatment group was recorded at 7:00 AM and 2:00 PM daily for three consecutive days on fortnightly basis.

Macroclimate:

Meteorological data (Temperature and Relative humidity) was collected from Department of Agricultural Meteorology, CCSHAU, Hisar.

Microclimate

Temperature and Relative humidity (RH):- Digital Indoor hygrometer thermometer was hanged in shed to record temperature and humidity of each shed. Upper roof temperature, false ceiling temperature and floor temperature of each treatment was recorded by infrared thermometer.

Statistical Method

The effect of different roofing materials with time was analysed using two-way repeated measures ANOVA, conducted through the General Linear Model procedure in SPSS software (version 20). This allowed for evaluation of both between group differences and time-based changes (within group differences) in microclimatic parameters.

Results and Discussion

Temperature (°C)

The shed temperature variation within-group and between-group when compared to the ambient macroclimate are presented in **Table 1** and depicted in **Figure 1**. Within groups, the asbestos roof (T1) showed the greatest fluctuation, with temperatures ranging from 26.23/ °C to 30.15/ °C, closely tracking macroclimatic variations (26.30–31.50/ °C), and indicating minimal thermal buffering. The glasswool plus white painted roof (T2) maintained the lowest and most stable temperatures (23.10–27.35/ °C) throughout, showing effective reduction of daily peaks and consistent moderation of internal heat gain. The E.P.E. sheet plus white painted roof (T3) exhibited intermediate within-group variation (24.27–29.27/ °C), offering moderate insulation performance. Between groups, T2 consistently recorded temperatures 4–7/ °C lower than the macroclimate, outperforming both T1 and T3, which showed smaller reductions of 1–4/ °C. These results demonstrate that insulated and reflective roofs (T2 and T3) significantly reduced both the range and mean of internal temperatures compared to the uninsulated asbestos roof (T1) and the macroclimate.

This heat map **(Figure 2)** illustrates the temperature variation over a 90-day period under different roof types (Asbestos, Glass Wool, EP Sheet) and the macroclimate. Each box shows the average shed temperature (°C), the colour scale indicates the temperature values, with red representing higher temperatures and green indicating cooler temperatures. The data suggests that the macroclimate experiences the highest temperatures, particularly at day 15 (31.5°C), while roof types like Glass Wool and EP Sheet maintain cooler temperatures.

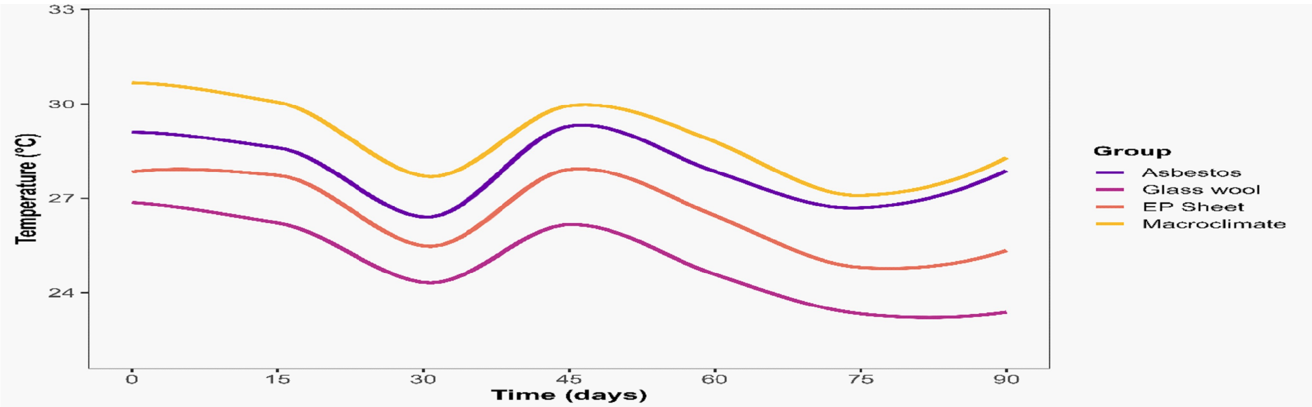
In the current study, roofs modified with glass wool insulation plus white paint (T2) maintained the lowest and most stable internal temperatures (23.10–27.35/ °C) throughout the 90-day observation period, consistently 4–7°C lower than the

Table 1: Comparison of Temperature (^{0}C) Variations for different Roofing Materials in Relation to Macroclimate Temperature.

	URT			FCT			Floor temperature		
	T_1 (Asbestos roof)	T_2 (Glasswool + White paint)	T_3 (E.P.E. Sheet + White paint)	T_1 (Asbestos roof)	T_2 (Glasswool + White paint)	T_3 (E.P.E. Sheet + White paint)	T_1 (Asbestos roof)	T_2 (Glasswool + White painted roof)	T_3 (E.P.E. Sheet + White paint)
0 day	$43.00^{Cbc}\pm0.7$	$39.00^{Ade}\pm0.1$	$40.85^{Be}\pm0.45$	$41.27^{Bc}\pm0.46$	$35.97^{Acd}\pm0.84$	$38.03^{Ade}\pm0.4$	$25.33^{Cabc}\pm0.8$	$23.32^{Abc}\pm0.72$	$24.53^{ABb}\pm0.8$
15 day	$44.95^{Bc}\pm0.95$	$39.87^{Ae}\pm0.46$	$41.60^{Ae}\pm0.22$	$41.03^{Bbc}\pm0.8$	$37.23^{Ad}\pm0.56$	$38.95^{Ae}\pm0.31$	$27.27^{Cc}\pm1.38$	$23.68^{Ac}\pm1.00$	$25.22^{ABb}\pm1.1$
30 day	$39.07^{Ba}\pm0.75$	$36.30^{Ab}\pm0.23$	$37.33^{Abc}\pm0.3$	$36.30^{Ba}\pm0.61$	$32.15^{Aab}\pm0.48$	$33.62^{Aa}\pm0.46$	$23.45^{Ca}\pm0.60$	$20.55^{Aa}\pm0.53$	$21.73^{ABa}\pm0.4$
45 day	$42.30^{Bb}\pm0.59$	$37.35^{Ac}\pm0.46$	$38.62^{Acd}\pm0.2$	$39.73^{Bbc}\pm0.7$	$35.58^{Acd}\pm0.38$	$36.78^{Ac}\pm0.38$	$27.15^{Cbc}\pm1.9$	$23.27^{Abc}\pm1.22$	$24.97^{ABb}\pm1.5$
60 day	$40.85^{Bab}\pm0.9$	$38.08^{Acd}\pm0.4$	$38.95^{Ad}\pm0.65$	$39.10^{Bb}\pm0.48$	$34.18^{Abc}\pm0.90$	$37.27^{Bcd}\pm0.4$	$25.00^{Cabc}\pm1.2$	$21.75^{Aabc}\pm1.00$	$23.78^{ABab}\pm1.2$
75 day	$38.78^{Ba}\pm0.66$	$33.98^{Aa}\pm0.07$	$34.57^{Aa}\pm0.33$	$36.40^{Ca}\pm0.68$	$30.85^{Aa}\pm0.45$	$33.97^{Ba}\pm0.06$	$24.47^{Cab}\pm2.2$	$20.68^{Aa}\pm1.56$	$22.07^{ABa}\pm1.8$
90 day	$43.20^{Bbc}\pm0.7$	$34.43^{Aa}\pm0.32$	$36.60^{Ab}\pm0.80$	$39.85^{Cbc}\pm0.5$	$32.10^{Aab}\pm1.08$	$35.52^{Bb}\pm0.41$	$24.72^{Cabc}\pm2.0$	$20.97^{Aab}\pm1.14$	$22.18^{Aa}\pm1.42$

Different superscripts indicate significant ($P < 0.05$) differences. Capital letters (A, B, C, D, E) denote differences between groups, while lowercase letters (a, b, c, d, e) indicate differences within a group over time.

Fig. 1 Temperature Trends under Different Roof Types in Relation to Macroclimate Temperature



macroclimate, while the EPE sheet plus white-painted roof (T3) performed moderately well, achieving 2–4°C reductions relative to the macroclimate and the asbestos roof (T1). These findings align with Kamal et al. (2016), who demonstrated that shading roofs with thatch polythene, agro-nets, and asbestos canvas combinations reduced internal temperatures compared to external conditions. The results of his study are consistent with Yanto et al. (2023) who showed that glass wool insulation reduced interior temperatures by 2°C in Malaysian homes because of superior insulation properties. Similarly, Narwaria (2020) and Amit et al. (2021) found that false ceilings using EPE sheets and reflective coatings effectively reduced shed temperatures by 1–1.5°C compared to asbestos roofs. The present finding is in agreement with Kamal et al. (2014) who recorded higher inner surface temperature of asbestos sheet in comparison to thatch roof during summer season and Maurya et al. (2023) who reported he average temperature of animal shed was significantly ($p<0.05$) lower in Roof with adjustable height (27.30±0.10), followed by Polycarbonate roof (28.28±0.04) and corrugated cemented sheet roof (29.46±0.16). Furthermore, Singh and Sharma (2023) reported that foam insulation under metal roofing reduced peak temperatures by 4–6°C, which corroborates the observed temperature reductions in this study for T2.

Relative Humidity (%)

The Relative humidity (RH) levels of different shed in comparison to microclimate shown in Table 2. Within groups, the asbestos roof (T1) showed RH values ranging from a high of 81.93% (day 0) to a low of 62.47% (day 75), indicating a gradual decrease over time as internal temperatures rose. The glasswool plus white painted roof (T2) maintained slightly lower and more stable RH levels (60.20–81.52%), reflecting better thermal insulation and moisture moderation. The E.P.E. sheet plus white painted roof (T3) displayed intermediate RH variation (61.27–82.78%), performing similarly to T1 at higher humidity but aligning more closely with T2 during lower RH phases. Between groups, all roof treatments recorded consistently higher RH than the macroclimate early in the period, but by day 75–90, macroclimate RH dropped more steeply than insulated roofs, which maintain moisture levels due to reduced heat penetration.

The present study revealed that insulated roofs (T2 and T3) sustained relatively higher and more stable RH (60.20–81.52% for T2) than the uninsulated asbestos roof (62.47–81.93 %) while maintaining lower fluctuations compared to the macroclimate. Narwaria (2020) similarly reported that insulated roofs using EPE sheets maintained higher average RH (75.72%) than asbestos roofs (73.28%) during peak afternoon hours, indicating that insulation not only moderates heat transfer but also preserves internal humidity by slowing air exchange and reducing moisture loss. In contrast to these results Amit et al. (2021) reported that there is non-significant effect on Relative humidity due to t microclimate alterations by roof modifications using EPE sheets as well as white paint. Present findings on RH in animal housing are in accordance with earlier reports of Kamal et al. (2014) who observed higher humidity in asbestos roofed house as compared to thatch, tree and agro-net and Maurya et al. (2023) showed that, in comparison to traditional structures, polycarbonate adjustable height sheds decreased RH (58.20±0.74% at 2:30 PM), which suggests that housing design plays a critical role in regulating both temperature and RH, thereby stabilising the THI.

Upper roof, false celeing and floor temeprature (°C)

Temperature variation over the time at upper roof, False celeing and floor surface are presented in Table 3 and depicted in Figure 3.

Upper Roof temperature within-group and between-group showed significant ($P<0.05$) differences across the different roof treatments. Within groups, the asbestos roof (T1) consistently recorded the highest URT values (38.78–44.95/ °C) while, glasswool plus white painted roof (T2) maintained the lowest and most stable URT levels (33.98–39.87/ °C), demonstrating

Table 2: Comparison of Relative Humidity (%) Variations for different Roofing Materials in Relation to Macroclimate Temperature

	T_1 (Asbestos roof)	T_2 (Glasswool + White paint)	T_3 (E.P.E. Sheet + White paint)	Macroclimate
0 day	81.93^{e}±0.38	81.52^{f}±0.02	82.78^{f}±0.71	85.50^{c}±02.02
15 day	75.32^{d}±0.44	72.68^{d}±0.29	74.00^{cd}±0.38	72.50^{bc}±03.75
30 day	76.60^{d}±0.53	74.68^{e}±0.24	75.05^{de}±0.10	75.00^{bc}±04.04
45 day	76.35^{d}±0.56	74.37^{e}±0.11	76.22^{e}±0.35	72.50^{bc}±04.33
60 day	73.58^{c}±0.54	71.95^{c}±0.10	73.03^{c}±0.64	70.00^{abc}±30.46
75 day	62.47^{a}±0.39	60.20^{a}±0.25	61.27^{a}±1.07	53.00^{a}±11.55
90 day	66.32^{b}±0.25	64.30^{b}±0.42	64.88^{b}±0.65	58.50^{ab}±05.48

Different superscripts indicate significant ($P < 0.05$) differences. Capital letters (A, B, C, D, E) denote differences between groups, while lowercase letters (a, b, c, d, e) indicate differences within a group over time.

Fig. 2 Heat map of Temperature across different Roof Types in relation to MacroclimateTemperature

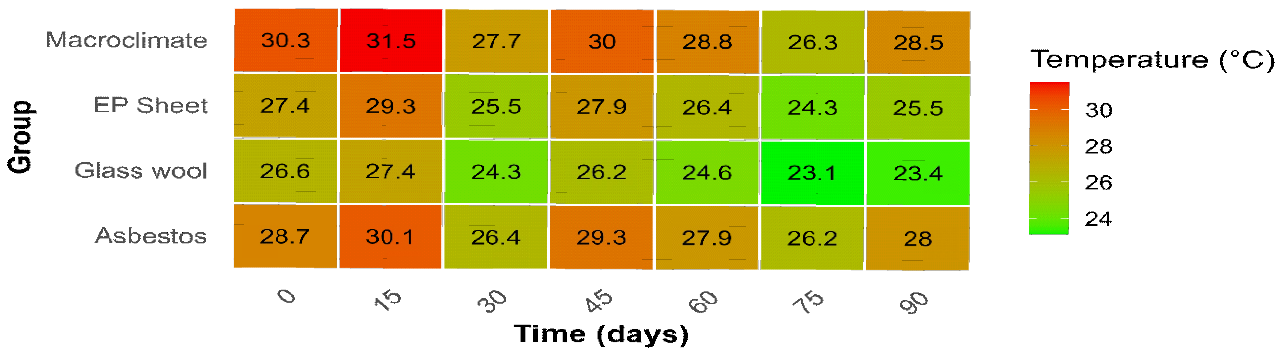


Table 3: Temperature variation across different roof types over the time at upper roof, False celeing and floor surface Temperature (℃)

	URT			FCT			Floor temperature		
	T_1 (Asbestos roof)	T_2 (Glasswool + White paint)	T_3 (E.P.E. Sheet + White paint)	T_1 (Asbestos roof)	T_2 (Glasswool + White paint)	T_3 (E.P.E. Sheet + White paint)	T_1 (Asbestos roof)	T_2 (Glasswool + White painted roof)	T_3 (E.P.E. Sheet + White paint)
0 day	$43.00^{Cbc}\pm0.7$	$39.00^{Ade}\pm0.1$	$40.85^{Be}\pm0.45$	$41.27^{Bc}\pm0.46$	$35.97^{Acd}\pm0.84$	$38.03^{Ade}\pm0.4$	$25.33^{Cabc}\pm0.8$	$23.32^{Abc}\pm0.72$	$24.53^{ABb}\pm0.8$
15 day	$44.95^{Bc}\pm0.95$	$39.87^{Ae}\pm0.46$	$41.60^{Ae}\pm0.22$	$41.03^{Bbc}\pm0.8$	$37.23^{Ad}\pm0.56$	$38.95^{Ae}\pm0.31$	$27.27^{Cc}\pm1.38$	$23.68^{Ac}\pm1.00$	$25.22^{ABb}\pm1.1$
30 day	$39.07^{Ba}\pm0.75$	$36.30^{Ab}\pm0.23$	$37.33^{Abc}\pm0.3$	$36.30^{Ba}\pm0.61$	$32.15^{Aab}\pm0.48$	$33.62^{Aa}\pm0.46$	$23.45^{Ca}\pm0.60$	$20.55^{Aa}\pm0.53$	$21.73^{ABa}\pm0.4$
45 day	$42.30^{Bb}\pm0.59$	$37.35^{Ac}\pm0.46$	$38.62^{Acd}\pm0.2$	$39.73^{Bbc}\pm0.7$	$35.58^{Acd}\pm0.38$	$36.78^{Ac}\pm0.38$	$27.15^{Cbc}\pm1.9$	$23.27^{Abc}\pm1.22$	$24.97^{ABb}\pm1.5$
60 day	$40.85^{Bab}\pm0.9$	$38.08^{Acd}\pm0.4$	$38.95^{Ad}\pm0.65$	$39.10^{Bb}\pm0.48$	$34.18^{Abc}\pm0.90$	$37.27^{Bcd}\pm0.4$	$25.00^{Cabc}\pm1.2$	$21.75^{Aabc}\pm1.00$	$23.78^{ABab}\pm1.2$
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90 day	$43.20^{Bbc}\pm0.7$	$34.43^{Aa}\pm0.32$	$36.60^{Ab}\pm0.80$	$39.85^{Cbc}\pm0.5$	$32.10^{Aab}\pm1.08$	$35.52^{Bb}\pm0.41$	$24.72^{Cabc}\pm2.0$	$20.97^{Aab}\pm1.14$	$22.18^{Aa}\pm1.42$

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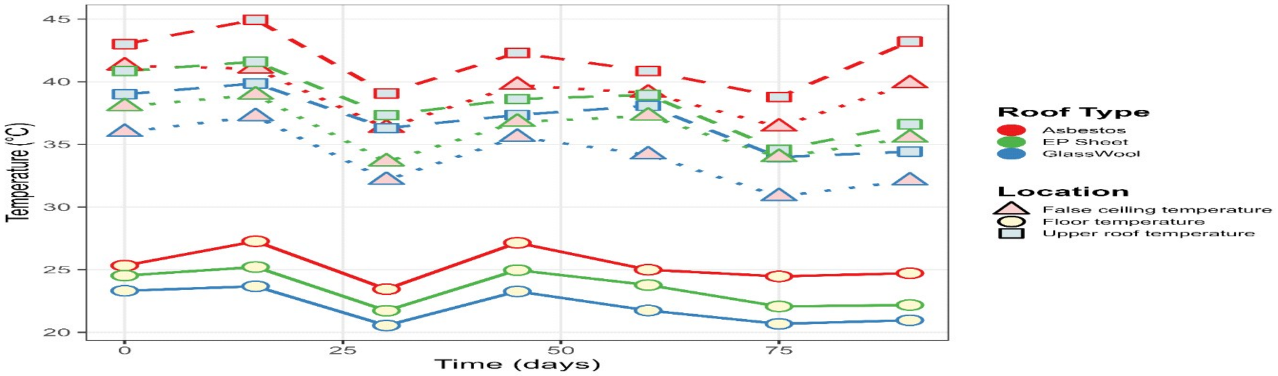
Fig. 3 Temperature variation (°C) over time by Roof type and Location



effective heat reduction and improved thermal comfort. The E.P.E. sheet plus white painted roof (T3) showed intermediate URT values (34.57–41.60/ °C). Between groups, T1 consistently exceeded T2 by approximately 4–6/ °C, highlighting the significant reduction achieved by insulation and reflective coating.

False ceiling temperature showed clear within-group and between-group variation among the roof treatments. Within groups, the asbestos roof (T1) consistently recorded the highest temperatures, ranging from 36.30/ °C to 41.27/ °C and glasswool plus white painted roof (T2) maintained the lowest and most stable FCT values (30.85–37.23/ °C), demonstrating effective reduction of heat transfer to floor surfaces. The E.P.E. sheet plus white painted roof (T3) displayed intermediate FCT values (33.62–38.95/ °C), performing moderately better than T1 but generally higher than T2 across time points. Between groups, T1 consistently exceeded T2 by 4–7/ °C, with T3 showing 1–4/ °C higher FCT than T2, highlighting the superior insulation effect of glasswool combined with a reflective roof coating.

Floor temperature values demonstrated distinct within-group and between-group differences across the roof treatments. Within groups, the asbestos roof (T1) consistently maintained the highest floor temperatures, ranging from 23.45/ °C to 27.27/ °C, while glasswool plus white painted roof (T2) recorded the lowest and most stable FT values (20.55–23.68/ °C), confirming its superior capacity to reduce internal floor heat levels. The E.P.E. sheet plus white painted roof (T3) showed intermediate floor temperatures (21.73–25.22/ °C), moderating heat gain better than T1 but less effectively than T2. Between groups, T1 consistently exceeded T2 by approximately 3–5/ °C, while T3 remained about 1–2/ °C higher than T2 across all time points.

The mean upper roof temperature (URT) in buffaloes housed under the asbestos roof (T1) remained highest (38.78–44.95/ °C), whereas buffaloes under the glass wool false ceiling with white paint (T2) consistently showed the lowest URT values (33.98–39.87/ °C). This trend aligns with Kamal et al. (2016), who found that shading roofs reduced the thermal stress load on livestock. The greater reduction in this study could be attributed to the combined thermal resistance of both the false ceiling insulation and the high reflectance of the white paint, which Sastry and Thomos (2012) reported to reflect up to 75% of incident solar radiation. The lower upper roof temperature under modified sheds demonstrates the direct physiological benefit of heat load reduction, supporting Kamal et al. (2013) who reported that outside surface temperature was significantly lower ($P<0.05$) for agro-net than thatch and asbestos. Which differs from the findings of Spain and Spiers (1996) who concluded that inside and outside surface of hutch in both shaded and un-shaded area did not differ significantly

False ceiling temperature (FCT)

The FCT was highest under T1 (36.30–41.27/ °C) and significantly lower under T2 (30.85–37.23/ °C). These findings are comparable to Narwaria (2020), who noted that the floor surface temperature under EPE-insulated false ceilings dropped by about 0.5–0.8°C compared to asbestos-only sheds. The temperature reduction between outside and inside surface of agro-net roof (48.77%) was higher followed by thatched roof (43.58%) and asbestos roof (27.15%) (Kamal et al. 2014). Sahu et al. (2018) results indicated that insulation by paddy straw ceiling under the asbestos had less surface temperature of 5 to 9 ºC. The improved thermal insulation effectively reduces radiant heat transfer, aligning with Maurya et al. (2023) who demonstrated the inner surface temperature of roofs designed with insulation were significantly ($p<0.05$) lower than Corrugated cemented sheet roof.

The lowest floor temperatures (FT) were consistently observed under T2 (20.55–23.68/ °C), followed by T3 (21.73–25.22/ °C), and the highest under T1 (23.45–27.27/ °C). This result agrees with Amit et al. (2021), who reported that EPE sheet roofing combined with reflective paint produced the lowest floor temperatures among various roof treatments. The findings are further supported by Singh and Sharma (2023) and Maurya et al. (2023) who demonstrated that thermal insulation materials effectively lower floor and internal surface temperatures by limiting heat gain during peak ambient temperatures.

Conclusion

The findings of this study clearly demonstrate that modifying conventional asbestos roofs with false ceilings using glass wool or expanded polyethylene (EPE) sheets, in combination with a reflective white paint coating, effectively reduces internal shed temperatures, stabilizes relative humidity, and lowers upper roof, false ceiling, and floor surface temperatures in the loose housing system of lactating Murrah buffaloes. Among the treatments, glass wool combined with white paint proved most effective, consistently maintaining the coolest and most stable microclimate. This integrated roof modification offers an accessible, low-cost, and practical strategy for dairy farmers in subtropical climates to mitigate heat stress, promote animal comfort, and safeguard milk production during hot seasons. It is recommended that further studies can be undertaken to validate these results under different housing systems, climatic conditions, and using alternative reflective and insulating materials to establish best practices for climate-resilient buffalo housing at farm level.

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