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Effect of roof modification on micro-climate of animal shed

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ABSTRACT

A study was conducted to compare the effect of roof modification with use of polycarbonate plastic sheet and its variable height on micro-climate of growing dairy heifers. The experiment was carried out on three sheds for three seasons, viz. hot-dry (summer) season, hot-humid (rainy) season and winter season. In control group (C), loose housing system was followed and corrugated cemented sheets were used as roofing material. In T1, polycarbonate sheets were used as roofing material with fixed height. In T2, polycarbonate sheets were used as roofing material with adjustable height. Daily ambient temperature (°C), dry and wet bulb temperature outside the shed (macro-climate) and inside the shed (micro-climate), Relative Humidity and Temperature Humidity Index were being recorded twice a day at 9.00 AM and 2: 30 PM for three continuous days at fortnightly interval. The average temperature of animal shed was significantly lower in T2 (27.30±0.10), followed by T1 (28.28±0.04) and C (29.46±0.16). In T2 lower temperature of shed than control was recorded during summer. Increasing the height of shed with ridge ventilation might have helped to dissipate heat easily in T2. The overall THI was significantly lower in T2 (76.50 ± 0.16) followed by T1 (77.91 ± 0.05) and higher in control (78.74 ± 0.25), which might be due to less penetration of solar radiation via reflective polycarbonate sheet and higher height of roof in T2. The micro-environment was more conducive and comfortable in T2 than control. Polycarbonate roofing with adjusted higher height may be a desirable choice for animal housing to mitigate heat stress in summer.

Keywords: Adjustable roof height, Animal sheds, Housing, Micro-climate, Roof modification

Roof is an integral part of housing, which prevents the access of solar radiations and rainwater to the livestock and ensures comfort to its inhabitants. Climate change, particularly global warming, may strongly affect production performance of farm animal's worldwide (Mote *et al*. 2014). High yielding animals are more sensitive to heat stress (Singh and Upadhyay 2009). The optimum range of temperature, humidity and Temperature Humidity Index (THI) for better performance of crossbred in subtropical region of India was found to be 19-26°C, 52-66% and 65-68, respectively (Mote *et al*. 2014). Housing design and the material used for the roof play an important role in the microclimate modification and reduction of radiant heat load inside the shed (Badino 2007). A wide variety of roof materials are available: thatch, clay tiles, wood, reinforced concrete cement (RCC), galvanized sheets, asbestos sheets, plastic sheets, etc. which should have at least one of the following properties: high reflectivity, low conductivity, low under-surface emissivity, correct roof profile (slope) and maximum practical height (Haque and Hussain 2011). Although, no single roof material possesses all the properties required to qualify as an ideal roof material, despite that efforts are always made in selection of roof material to provide maximum comfort to the animals. Polycarbonate is a strong thermoplastic material that is light in weight and can withstand extremely low and high temperatures. This durable and practical roofing material is perfect for roofing animal houses. These panels are resistant to heat, sunlight, snow, and rain, which enable them to last for many years without fading or discoloring (Sanjay and Prabha Chand 2008). The modified roof (normal roof fitted with woven polypropylene shade cloth) in comparison to normal roof provides better microclimate to minimize thermal stress and improves the productive and reproductive performance in Friesian crossbred cows during hot-humid season (Khongdee *et al.* 2010). Effectiveness of roof may further be improved by developing techniques of adjustment of roof height, eave length and angle of eave. Due to high capital investment in permanent animal housing structures, frequent replacement of roofing material may neither be technically feasible nor economically viable. Altering the height of the roof according to climatic fluctuations and hence modifying the micro-climate of the animal house for more comfort levels may be an innovative approach towards roof modification. As per the perusal of literature, the study on roof height adjustment in livestock has not been tired and any scientific report exists. Therefore, the

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present study was conducted to study the effect of roof modification with adjustable roof height on micro-climate of animal shed.

MATERIALS AND METHODS

The present study was carried out on three types of sheds constructed at Cattle and Buffalo Farm, ICAR-Indian Veterinary Research Institute, Izatnagar in the year 2017-18. The study was conducted for a period of one year which consisted of three climatic phases, viz. hot-dry (summer) season, hot-humid (rainy) season and winter season. The study area was located at an altitude of 169 m above the mean sea level, at the latitude of 28° 29' North and 79° 24' East. A sub-tropical climate with maximum ambient temperature (45°C) and minimum temperature (approximately 2°C) prevails in the area. However, the Relative Humidity (RH) ranged between 45.46 and 93.93%. Macro-climatic parameters were obtained from the Division of Physiology and Climatology of the institute. Ambient temperature, relative humidity, temperature humidity index (THI) of sheds, inner surface of roofs and floor temperature were recorded twice a day on fortnightly basis.

Experimental design and animal shed structure: Control (C): In control group (C) loose housing system was followed with 2 m^2 space per animal in covered area and 4 m^2 per animal in open area. Corrugated cemented sheets were used as roofing material. Height of the roof at centre was kept 12 feet and height at eaves was 10 feet. Treatment 1 (T1): Similarly, animal house of same height and dimensions as that of control but having polycarbonate sheet as roofing material was constructed. Treatment 2 (T2): Animal house having similar dimensions and polycarbonate sheet as roofing material but with adjustable height. Height at eaves was adjusted to 11 feet (3.35 m) at one side and 9 feet (2.7 m) at the other side, keeping the height at center to 14 feet (only for hot-dry period). Height at eaves was kept 2.5-2.7 m and the height at center was 3.5 m (for hot-humid period). The roof was arranged like a ridge system of ventilation for hot air in shed to pass from the roof itself. A gap of two feet was provided for ridge ventilation with one side of roof overhanging the other. The center of roof was made open continuous ridge for elimination of hot air from the shed. The height at center was reduced to 10 feet (3 m) for winter. The ridge between the roofs was closed to make the shed slightly warmer.

Measurement of macro and microclimatic variables: Daily ambient temperature, dry and wet bulb temperature of outside the shed (macro-climate) and inside the shed (micro-climate) in various groups was recorded at 9.00 AM and 2:30 PM of Indian Standard Time (IST) for three continuous days at fortnightly interval. The thermometers were hung at equal heights above to the animal body surface level using thread under the shed in each group. In different groups RH values (%) was calculated using dry and wet bulb thermometer readings via hygrometric chart, during the study period. Surface Temperature (ST) of the inner side of roof and ST of floor was recorded using hand held infrared surface thermometer. THI values were calculated using Mc Dowell (1972):

$$THI=0.72(\text{wet bulb temperature} + \text{dry bulb temperature}) + 40.6$$

Statistical analysis: Descriptive statistics were calculated for daily minimum and maximum temperature; RH and THI with all means were represented as Mean ± SEM. These values in different groups were compared by two-way analysis of variance (ANOVA) without interaction using general linear model. When the p-value was <0.05, then all analysis was considered to be significantly different. All the analyses were performed using SPSS 11.0 statistical package.

RESULTS AND DISCUSSION

Macro-climatic parameters during the summer season: The mean values of solar radiation (W/m^2), wind speed (m/sec), ambient temperature (°C) outside the shed, RH and THI during the summer season were 202±2.41, 0.37±0.03, 29.04±0.20, 44.59±1.81 and 82.84±0.33, respectively. The macroclimatic conditions were more stressful during last fortnights of the experimental period.

Temperature (°C) of animal shed during the summer: The temperature (°C) of animal shed during the summer has been presented in Table 1. The average temperature of animal shed was significantly ($p<0.05$) lower in T2 (27.30±0.10), followed by T1 (28.28±0.04) and C (29.46±0.16). The temperature of sheds at 9:00 AM and 2:30 PM were also significantly ($p<0.05$) lower in T2 followed by T1 and highest in C, during all the fortnights (Table 1). In T2, lower temperature of shed than control was recorded during summer which may be due to higher height of house and ridge system of ventilation which allowed the hot air accumulated to pass from the roof itself and hence maintained a slightly lower shed temperature. Increasing the height of shed with ridge ventilation might have helped to dissipate heat easily in T2. 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 Jat *et al.* (2005) who reported that higher temperature of asbestos roofed house as compared to thatch and mud plaster roof. Roy and Chatterjee (2010) recorded higher temperature in GI sheet roof with brick/mud floor in comparison to tile roof (35.95±1.2°C) with brick floor and brick/jute stick wall during summer season. Polystyrene or polyurethane insulation layers had the capability of reducing the heat load by more than 50% (Sanjay and Prabha Chand 2008). Similar findings on temperature of micro-environment using clothing were reported by Eigenberg *et al*. (2009) and Khongdee *et al*. (2010) which could be more efficient way to minimize heat stress than that of normal roof.

Relative humidity (%) of sheds during the summer: The RH at 9:00 AM was significantly ($p<0.05$) higher than at 2:30 PM, irrespective of treatment. Present findings on RH in animal housing are in accordance with earlier reports (Sharma and Singh 2002, Kaur and Singh 2004 and

Table 1. Micro-environment of animal sheds during summer (hot dry condition)

Parameters	Time	Corrugated cemented sheet roof (C)	Polycarbonate roof (T1)	Roof with adjustable height (T2)
Mean ± SEM of temperature (°C)	9:00 AM	24.11±0.13^{a}	22.84±0.04^{b}	21.86±0.17^{c}
	2:30 PM	34.82±0.25^{a}	33.73±0.07^{b}	32.74±0.13^{c}
	Average	29.46±0.16^{a}	28.28±0.04^{b}	27.30±0.10^{c}
Mean± SEM of relative humidity (%)	9:00 AM	70.37±0.21^{a}	70.26±0.48^{a}	66.56±0.30^{b}
	2:30 PM	62.23±0.40^{a}	61.11±0.39^{a}	58.20±0.74^{b}
	Average	66.30±0.30^{a}	65.68±0.23^{a}	62.38±0.30^{b}
Mean± SEM of temperature humidity index (THI)	9:00 AM	76.03±0.28^{a}	75.98±0.07^{a}	74.39±0.39^{b}
	2:30 PM	81.44±0.23^{a}	79.84±0.09^{b}	78.61±0.08^{b}
	Average	78.74±0.25^{a}	77.91±0.05^{a}	76.50±0.16^{b}
Mean± SEM of inner surface temperature (°C) of roofs	9:00 AM	39.58±0.24^{a}	38.12±0.17^{ab}	37.54±0.18^{b}
	2:30 AM	46.59±0.20	44.78±0.24	44.22±0.26
	Average	43.09±0.21	41.45±0.11	40.87±0.04
Mean± SEM of Surface temperature (°C) of floor	9:00 AM	32.44±0.19^{a}	31.14±0.47^{ab}	30.60±0.49^{b}
	2:30 PM	39.17±0.26^{a}	37.35±0.82^{ab}	36.16±0.74^{b}
	Average	35.81±0.22^{a}	34.24±0.53^{ab}	33.38±0.44^{b}

Means values between 9:00 AM and 2:30 PM differ significantly ($p<0.05$) within the treatments.Means bearing different superscript (a, b, c) differ significantly ($p<0.05$) within the row.

Kamal *et al.* 2014) who observed higher humidity in asbestos roofed house as compared to thatch, tree and agro-net.

Temperature humidity index of sheds during the summer: The THI under different roofing materials at during the summer is presented in Table 1. The overall THI was significantly ($p<0.05$) lower in T2 followed by T1 and higher in control, both at 9:00 AM and 2:30 PM. Higher ambient temperature coupled with higher RH, contributed more stress in dairy cattle (Badino 2007). The lower value of THI in group T1, T2 as compared to C might be due to less penetration of solar radiation via reflective polycarbonate sheet and higher height of roof in T2. The present findings are comparable with previous reports (Jat *et al.* 2005 and Kamal *et al.* 2014) who reported significantly ($p<0.05$) higher THI at evening than morning hours and concluded that higher THI in loose house covered with asbestos sheet as compared to thatch, mud plastered roof and agro-net roof. Similarly, Patil *et al.* (2014) reported lower values of THI under modified roof shed (thatch + asbestos) as compared to asbestos shed and painted shed in all periods of trial.

Inner surface temperature (°C) of different roofing materials during the summer: The inner surface temperature at 9:00 AM and 2:30 PM were significantly ($p<0.05$) lower in T2 followed by T1 and highest in C, during the initial three fortnights, but no significant difference was observed between the groups after 3rd fortnight (Table 1). Maximum temperature could be observed in C followed by T2. CCS roof absorbs the heat and passes to the animal house. Similarly, polycarbonate being heat and UV resistant did not allow heat to pass and thus provided better microclimate in T2 and T1 as compared to control.

Surface temperature (°C) of floor during the summer: The surface temperature of floor at 9:00 AM and 2:30 PM were significantly ($p<0.05$) lower in T2 followed by T1 and highest in C, during all the fortnights (Table 1). The temperature, RH and THI was comparatively lower in T2 leading to lower floor temperature as compared to control. However, floor temperature between C and T1 was statistically non-significant. Similarly, in T1 and T2, no significant difference was observed.

Effect of modified housing on macro-climate during rainy season: The average solar radiation (W/m^2), wind speed (m/sec), ambient temperature (°C) outside the shed, RH and THI were 158.80±5.06, 0.46±0.03, 28.95±0.17, 78.24±0.79 and 84.55±0.19, respectively. The macroclimatic conditions were more stressful during afternoon as compared to morning hours.

Temperature (°C) of sheds during rainy season: The overall average temperature was significantly ($p<0.05$) lower in T2 (28.18±0.11) as compared to T1 (29.74±0.19) and C (30.55±0.06). The temperature of sheds at 9:00 AM and 2:30 PM were significantly lower ($p<0.05$) in T2 followed by T1 and highest in C (Table 2). In T2 lower temperature of shed than control was recorded during rainy season which may be due to higher height of house and ridge system of ventilation which allowed the hot air accumulated to pass from the roof itself and hence maintained a slightly lower shed temperature. Increasing the height of shed with ridge ventilation might have helped to dissipate heat easily in T2. The present findings are in agreement with Kamal *et al.* (2013) and Jat *et al.* (2005) who reported higher shed temperature of asbestos sheet roofing material in comparison to thatched roof, mud-plaster roof and agro-net sheet roof house during rainy season. Asbestos roofed houses had higher temperature than the tile roofed house (Sivakumar 2002). However, contrary to our results Roy and Chatterjee (2010) reported that polythene sheet roof had the lowest minimum and higher maximum temperature

Table 2. Micro-environment of animal sheds during rainy season (hot-humid condition)

Parameter	Time	Corrugated cemented sheet roof (C)	Polycarbonate roof (T1)	Roof with adjustable height (T2)
Mean ± SEM of temperature (°C)	9:00 AM	25.34±0.09[a]	24.54±0.20[b]	22.86±0.17[c]
	2:30 PM	35.75±0.15[a]	34.94±0.32[b]	33.37±0.15[c]
	Average	30.55±0.06[a]	29.74±0.19[b]	28.18±0.11[c]
Mean± SEM of relative humidity (%)	9:00 AM	85.67±0.22[a]	84.41±0.62 [ab]	79.95±0.40[c]
	2:30 PM	80.17±0.41[a]	79.79±0.96[b]	74.22±0.26[c]
	Average	82.92±0.12[a]	82.10±0.76 [ab]	77.08±0.31[c]
Mean± SEM of temperature humidity index (THI)	9:00 AM	77.28±0.20[a]	76.69±0.24[a]	74.34±0.23[b]
	2:30 PM	81.33±0.19[a]	80.01±0.09[ab]	78.78±0.18[b]
	Average	79.30±0.18[a]	78.35±0.16 [a]	76.56±0.21[b]
Mean± SEM of inner surface temperature (°C) of roofs	9:00 AM	40.40±0.04[a]	39.24±0.24[ab]	38.49±0.28[b]
	2:30 AM	48.94±0.56[a]	48.14±0.33[ab]	47.02±0.19[b]
	Average	44.67±0.27[a]	43.69±0.14[ab]	42.75±0.19[b]
Mean± SEM of Surface temperature (°C) of floor	9:00 AM	34.79±0.15[a]	33.00±0.52[ab]	32.35±0.35[b]
	2:30 PM	39.49±0.28[a]	37.82±0.49[ab]	36.81±0.41[b]
	Average	37.14±0.21[a]	35.41±0.45[ab]	34.58±0.28[b]

Means values between 9:00 AM and 2:30 PM differ significantly (p<0.05) within the treatments. Means bearing different superscript differ significantly (p<0.05) within the row.

as compared to GI sheet, and tile roof shade structure in rainy season. A compound roof system developed with a combination of radiation reflectors and thermal insulation demonstrated substantial lowering of the heat conducted through a concrete roof (Alvarado *et al.* 2009).

Relative humidity (%) of sheds during rainy season: The RH at 9:00 AM during the first fortnight in C, T1 and T2 was 80.80±1.22, 80.05±1.87 and 76.80±2.04%, which increased to 86.72±1.52, 85.72 ±2.23 and 79.70±2.65 % respectively, at last fortnight. Similarly, RH at 2:30 PM increased from 73.50±0.92, 72.70±1.29 and 69.60±1.92% to 83.51±1.98, 83.51±1.29 and 73.23±1.06 % for C, T1 and T2 respectively, during the rainy season. The RH at 9:00 AM was significantly (p<0.05) higher than at 2:30 PM irrespective of treatment. The RH at 9:00 AM and 2:30 PM was significantly (p<0.05) higher in C, followed by T1 as compared to T2 during all the fortnights. The negative diurnal changes in RH were observed in all the treatment sheds during rainy season due to rise in environmental temperature from morning to mid-day which could be a routine phenomenon as reported earlier by Kaur and Singh (2004). The present finding are also supported by Roy and Chatterjee (2010), who reported significantly higher in morning and evening in all the shelters (GI sheet, tiles and polythene shade) during rainy season indicating higher stress on the animals (Adam 2006), whereas, Das (2012) observed highest RH in GI sheet roof (80.00±1.90) during rainy season. Asbestos roofed houses had higher relative humidity than the tile roofed house (Sivakumar 2017). The RH under T2 was found to be minimum which might be due to the fact that this system of housing allowed the floor to become dry quickly and provided proper ventilation.

Temperature humidity index (THI) of sheds during rainy season: The THI recorded fortnightly at 9:00 AM was significantly (p<0.05) lower from THI at 2:30 PM in all the treatments groups. Lower values of THI in T2 compared to control indicates more conducive micro-environment, which may be due to less heat penetration and effective ventilation viz. higher height of roof. The present finding is also supported by Khongdee (2008), who concluded that the difference between maximum and minimum THI during the rainy season was lower suggesting that the dairy cows were exposed consistently to heat stress during the rainy season. However, the shade of polypropylene had significantly lower ambient temperature and THI (p<0.05) for 5 h and 5 h 30 minute respectively, the difference most likely due to the reduction in re-radiated heat in the shaded area. Pusta *et al*. (2006) reported higher THI (>72) in pasture heifers in the month of rainy season as compared to cows during lactation. Jat *et al*. (2005) recorded higher THI in asbestos in morning (81.52±0.35) and evening (85.71±0.51) as compared to mud plaster and less in thatch during rainy season, whereas, Das (2012) and Roy and Chatterjee (2010) observed higher THI (83.48±0.52) under GI sheet roof.

Inner surface temperature (°C) of roofing materials during rainy season: Higher temperature was observed in C followed by T1 and T2 (Table 2). Polycarbonate being reflective and UV resistant did not allow heat to pass and thus provide better microclimate as compared to control in T2 and T1. The present findings are in agreement with Kamal *et al.* (2013) who recorded higher inner surface temperature of asbestos sheet in comparison to thatched roof and agro-net roof during rainy season.

Surface temperature (°C) of floor during rainy season: The surface temperature of floor at 9:00 AM and 2:30 PM were significantly (p<0.05) lower in T2 followed by T1 and highest in C, during all the fortnights. The temperature, RH and THI was comparatively lower in T2 leading to lower floor temperature as compared to control (Table 2).

Table 3. Micro-environment of animal sheds during winter

Parameter	Time	Corrugated cemented sheet roof (C)	Polycarbonate roof (T1)	Roof with adjustable height (T2)
Mean ± SEM of temperature (°C)	9:00 AM	14.51±0.09[a]	14.34±0.20[a]	15.06±0.17[b]
	2:30 PM	21.47±0.15	21.07±0.32	21.58±0.15
	Average	17.99±0.06[a]	17.70±0.19[a]	18.32±0.11[b]
Mean± SEM of relative humidity (%)	9:00 AM	86.75±0.22[a]	84.75±0.62[ab]	83.51±0.40[b]
	2:30 PM	73.77±0.41	72.81±0.96	73.10±0.26
	Average	80.26±0.12[a]	78.78±0.76[b]	78.78±0.31[b]
Mean± SEM of temperature humidity index (THI)	9:00 AM	60.51±0.28[a]	61.33±0.07[a]	64.93±0.39[b]
	2:30 PM	67.99±0.23[a]	68.77±0.09[a]	69.95±0.08[b]
	Average	64.25±0.25[a]	65.05±0.05[a]	67.45±0.16[b]
Mean± SEM of inner surface temperature (°C) of roofs	9:00 AM	13.10±0.04[a]	13.55±0.24[a]	14.33±0.28[b]
	2:30 PM	24.87±0.56	24.38±0.33	24.62±0.19
	Average	18.98±0.27[a]	18.96±0.14[a]	19.48±0.19[b]
Mean± SEM of Surface temperature (°C) of floor	9:00 AM	14.20±0.19[a]	14.28±0.47[a]	15.11±0.49[b]
	2:30 PM	23.81±0.26[a]	23.44±0.82[a]	24.16±0.74[b]
	Average	19.01±0.22[a]	18.86±0.53[a]	19.64±0.44[b]

Means values between 9:00 AM and 2:30 PM differ significantly ($p<0.05$) within the treatments. Means bearing different superscript differ significantly ($p<0.05$) row wise.

Effect of housing modification on macro climate during winter season: The average solar radiation (W/m^2), wind speed (m/sec), ambient temperature (°C) outside the shed, RH and THI were 100.99±5.06, 0.76±0.09, 16.88±0.19, 81.87±0.21 and 69.30±0.19, respectively. The macro-climatic extremes were in animal`s tolerable range during the winter season.

Temperature (°C) of experimental sheds during winter: Table 3 reveals that the shed temperature at 9:00 AM was significantly lower than that at 2:30 PM irrespective of the treatment groups. Overall, the temperature of shed in T2 was significantly warmer than T1 and C in the morning hours, which may be attributed to lowered height of roof in T2 leading to more warmth in the shed. The present findings are in accordance with Sivakumar *et al.* (2017) who reported no significant difference in the micro-climate of thatch, tile, metal and cemented roof in winter season.

Relative humidity (%) of experimental sheds during the winter: The RH of microclimate during winter season has been presented in Table 3. The table reveals that the RH was found to be lower ($p<0.05$) in T2 as compared to T1 and C in morning hours. However, no significant difference was observed within the groups during afternoon. The negative diurnal changes in RH were observed in all the sheds during winter season due to rise in environmental temperature from morning to mid-day as routine phenomenon as reported earliest also by Roy and Chatterjee (2010).

Temperature humidity index (THI) during the winter: The THI of micro-climate under different roofing materials during the experimental period are presented in Table 3. The perusal of table reveals that both at 9:00 AM and 2:30 PM, THI was found to be significantly more ($p<0.05$) in T2 followed by T1 and C, indicating more comfort and warmth in T2 as compared to T1 and C. This might be due to decreased height of roof in T2 leading to maintenance of warm micro-environment inside the shed. However, Sivakumar *et al.,* (2017) reported no significant difference in the THI of animal houses with thatch, tile, metal and cemented roof in winter season.

Inner surface temperature (°C) of different roofing materials during the winter: Inner surface temperature of different roofing materials has been presented in table 3. The inner surface temperature was warmer ($p<0.05$) in T2 as compared to C and T1 at 9:00 AM. However, no significant difference was found within the groups at 2:30 PM. The present findings are supported by Sivakumar *et al.* (2017) who also reported no significant difference in the temperature of different roofing materials during winter season.

Surface temperature (°C) of floor during the winter: Floor temperature of different sheds has been presented in Table 3. Overall average floor temperature was comparatively warmer ($P<0.05$) in T2 (19.64± 0.44°C) as compared to C (19.01± 0.22°C) and T1(18.86± 0.53°C). Similarly, floor temperature was warmer ($P<0.05$) in T2 as compared to C and T1 both at 9:00 AM and 2:30 PM.

It was concluded that the micro-environment in polycarbonate sheet roofed shed with adjustable height was more conducive than control (asbestos sheet roofing) which could be beneficial for better growth and physiological performance in livestock. Reflective polycarbonate roofing with adjusted higher height may be the desirable choice for animal housing in view of mitigating heat stress during the summer and hot-humid climate.

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