EFFICIENCY OF INSTALLED COOLING SYSTEMS IN DAIRY BARNS DURING HOT SEASON

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Abstract
Hot season of the year has profound effects on the production, health, profitability, and welfare of dairy cows. The objective of this study was to evaluate the efficacy of cooling systems in controlling the microclimate condition inside the two dairy barns. There was set out to compare the ambient conditions inside the barn with environmental weather data obtained from local meteorological station. The experiment was carried out at the height of summer (from 15th of June to 31st of August) in two familiar dairy farms. Within the barns air temperature, relative humidity and their ratio expressed as temperature humidity index (THI) were measured hourly during the trial period using data loggers. The Pearson's coefficient of correlation demonstrates that climate condition inside the barns and the official local meteorological station significantly correlate. The air temperature and THI were significantly higher in the Farm 1 (1.53±0.239^{0}C higher, t=6.420; p<0.001, and 2.05±0.344 units higher, t=5.973; p<0.001, respectively) and in the Farm 2 (1.65±0.252^{0}C higher, t=6.549; p<0.001, and 2.12±0.357 units higher, t=5.927; p<0.001, respectively) compare with the environmental weather data. The method of GLM, multivariate procedure, showed that there was statistical significant differences in the minimal values for daily microclimate parameters inside the barns before and after installation of cooling equipment. However, the interaction between the farm and cooling system, months and days of hot summer season showed statistical significant influence on the microclimate conditions inside the cow barns with exception for the maximal values for air temperature and THI. In conclusion, due to farm specific and unpredictable variability in climate conditions inside the cow barns and their correlation with environmental weather data, the installed cooling systems could provide better climate zone in the barns for increased milk production but couldn't completely satisfy capacity of cooling during the day time with highest air temperature.

Keywords: climate condition, dairy cow, temperature-humidity index.

Introduction

Environmental conditions, such as solar radiation, high air temperature and relative humidity are the main stress factors for dairy cows (Silanikove, 2000). The etiology of heat stress consists in failure to maintain the core body thermo-neutrality with increasing ambient temperature and humidity. To gauge the level of heat stress in cattle, a composite index of heat and humidity, the temperature-humidity index (THI), is a widely used metric (Bohmanova et al., 2007). A cow may start to show signs of heat stress beginning at a temperature-humidity index (THI) of around 68 (Zimbelman et al., 2009). Exposure of dairy cows to a thermal environment is a major risk factor for decreased milk production; especially in high-yielding cows than low-yielding ones (Kadzere et al., 2002) due to combined accumulation of heat gained from the environment and metabolic heat (Rhoads et al., 2009). When dairy cows are under heat stress, than accumulated heat exceeds the body capacity for heat loss by radiation, convection and conduction. Recently, it has been demonstrated that a trend exists in the dairy industry toward fewer and larger dairy farms housing more cows under one roof (Winsten et al., 2010), which might increase the risk of suboptimal climate conditions. In order to reducing heat load of dairy cows rearing under high ambient temperatures accomplished with the higher metabolic heat production, additional cooling measures during the year season of thermal stress are required (Collier et al., *2006*). Previous studies have shown that evaporative cooling is effective in reducing thermal stress on lactating dairy cows in worm climates (Berman, 2009). The climatic condition in Republic of Macedonia is Continental – Mediterranean, characterized with very hot and dry periods during the summer. The temperature rises up to 40^0C in the summer season. In this zone, animals are exposed to heat stress over than three months annually. Extended periods of excessive ambient heat negatively affect the productive performance and welfare of dairy cattle, causing serious economic losses to the dairy industries.This research was following the trial that was done the year before aimed to underline the detrimental impact of environmental thermal stress in terms of milk yield losses of dairy cows rearing in local conditions in the Republic of Macedonia (Trajchev et al., 2016). Therefore, the objectives of this research were to compare the microclimate conditions of two dairy facilities after installation of cooling systems for reduction of heat stress with the climate data recorded from the nearby official meteorological stations.

Material and methods

The experiment was carried out at the height of summer (from 15th of June to 31st of August) in two familiar dairy farms (1 and 2). The main reason for continuing the experiment from the previous year was installation of cooling system in two dairy farms for microclimate controlling. These farms previously didn't have any cooling system inside barns. The dairy farms included in the survey are located in the municipality of Strumica, southeastern region of Republic of Macedonia. With the small exceptions, the farms included have similar management system. Management practice in farm 1 and farm 2 is production in tie-stalls with enclosed shed. The volume of the farm 1 is around $192m^3$ (8m width * 8m length * 3m height). The volume of the farm 2 is around $600m^3$ (10m width * 20m length * 3m height). These farms are practicing intensive dairy cattle breeding, based on high milk yield breed. Totally 18 dairy cows from Holstein black-white breed were subjected to the study (6 cows in farm 1 and 12 cows in farm 2). Cows had free access to drinking water in the holding pen. Milking of cows is performed with transferable milking system. The cows were milking twice daily (morning and evening milking) with some exceptions of dairy cows in the period of early lactation when were milking three times daily (morning, afternoon and evening milking). The summer season of research was divided in three reporting periods: the first reporting period (from the 15th of June to the 30th of June), the second reporting period (from the 1st of July to the 31st of July) and the third reporting period (from the 1st of August to the 31st of August). Every day during the trial period hourly was measured weather parameters in the both of observed farms. In the first reporting period from the June 15th 2016 until June 30th 2016 the installation of the cooling equipment on the farms has been finished. Furthermore, monitoring and testing of the equipment was implemented. The cooling systems on the both farms were started when the first heat wave was noticed. The installed equipment in the barns of the farm 1 included one fan and three fans plus fogging system in the farm 2. The fans installed in the both of farms can be started in two ways: manually and automatically. Fans were set to start automatically when the air temperature in the barns reaches 30^0C, and they shut down when the air temperature in the barns falls down to 28^0C. For that aim, inside the electrical box a thermal probe (thermostat) was installed. The installed fogging system on the farm 2 is not a professional system as the professional one is too expensive for the small farmers. For that reason we decided to install the fogging system which is similar as that used in the vegetable production (green house). The fogging system was set to start automatically when the fans turn on, and they switch off when the fans shut down. This is regulated by the electromagnetic water valve. During the second and the third reporting period the cooling system installed in the both dairy farms (fan/fans plus fogging) was working depending of the air temperature in the barns. The cooling systems on the both farms were started when the first heat wave was noticed. For prompt observation of the variations in weather parameters, the automated temperature and humidity data loggers were set inside the barns. The air temperature inside barns (T_IB), relative humidity (RH_IB) and their interaction represent as temperature-humidity index (THI_IB) were measured hourly during the trial period. The data for environmental weather parameters: the air daily temperatures (T_E) - average minimal and maximal air temperature then the daily relative humidity (RH_E) - minimal and maximal, were obtained by the National Hydro-meteorological Service of Republic of Macedonia from the meteorological station located in the region of Strumica. Their interaction expressed as environmental temperature-humidity index (THI_E) was calculated from obtained data. The maximum distance between each farm and meteorological weather station was around 20 km. The calculation of the average daily relative humidity was done as mean value from the minimal and maximal daily relative humidity.

Temperature–Humidity Index (THI) was calculated according to Hahn (1999) as:

$$THI\_IB = (0.81 * T\_IB) + (RH\_IB/100) * (T\_IB - 14.4) + 46.4$$

$$THI\_E = (0.81 * T\_E) + (RH\_E/100) * (T\_E - 14.4) + 46.4$$

Statistically, daily average, minimal and maximal air temperature and relative humidity were calculated from the hourly data gained from the automated temperature and humidity data loggers. Weather data in this experiment were analyzed by using the descriptive statistics and GLM, multivariate procedure of software SPSS 20.0. Statistically, the data were presented as mean ± standard error of the mean. The statistical signification of the differences between daily weather data of the official meteorological station and the climate loggers were assessed using a paired *t*-test.

Results and discussion

Variations in the average daily values for the air temperature inside the cow barns and environmental air temperature are shown on figure 1. It is obviously that the ambient air temperature inside the dairy facilities is quite higher comparing with the average environmental air temperature. There is a trend of decreasing of mean air temperature inside the barns after installation of cooling equipment.

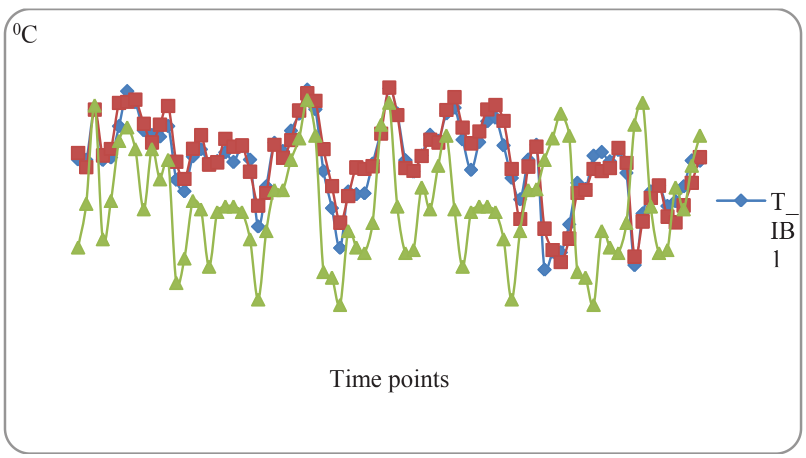

Figure 1. Variations in the mean daily air temperature readings between on-farm loggers and meteorological station readings during the trial period

Variations in the average daily values for the air relative humidity inside the cow barns and the environmental air relative humidity are shown on figure 2. There wasn't a big difference in the average daily values for air relative humidity in the cow barns and the environment. In the third reporting period there were recorded highest average values for daily air relative humidity.

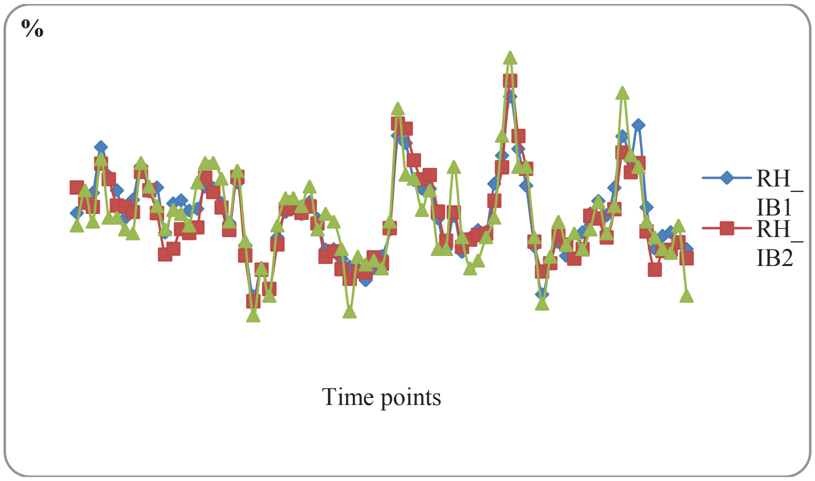

Figure 2. Variations in the mean daily air relative humidity readings between on-farm loggers and meteorological station readings during the trial period

Variations in the average daily values for THI inside the cow barns and the environmental air relative humidity are shown on figure 3. Continuously, during the whole trial period the mean daily values for THI were highest inside the cow barns compare with the environmental data for average daily THI.

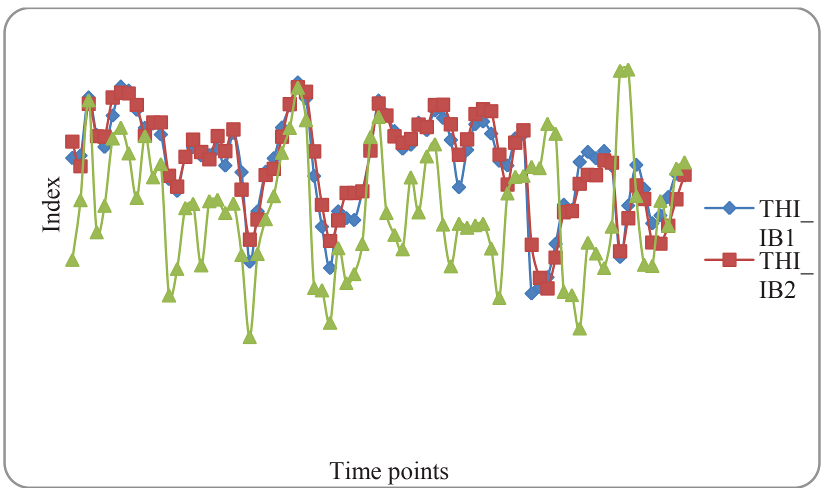

Figure 3. Variations in the mean daily temperature-humidity index (THI) readings between on-farm loggers and meteorological station readings during the trial period

Measures of correlations demonstrate that climate condition inside the barns and the official local meteorological station significantly correlate (table 1). It was found that air temperature and THI were significantly higher in the farm 1 (1.53±0.239^{0}C higher, t=6.420; p<0.001, and 2.05±0.344 units higher, t=5.973; p<0.001, respectively) and in the farm 2 (1.65±0.252^{0}C higher, t=6.549; p<0.001, and 2.12±0.357 units higher, t=5.927; p<0.001, respectively) compare with the environmental weather data. The relative humidity was 0.15±0.314% higher in the farm 1 than at the official meteorological station and this difference wasn't statistically significant (t=0.467). When compare the relative humidity in the farm 2 with data from the official meteorological station, then the relative humidity was higher at the environment than in the cow barns of the farm 2 (0.39±0.323%) and this difference wasn't statistically significant (t=1.232). The results from the statistical GLM model, multivariate procedure for influence of fixed variables on weather data inside the dairy facilities are shown in table 2.

Table 1. Mean ambient temperature, relative humidity and temperature-humidity index onsite and at the official meteorological station

	Farm 1	Farm 2
T_IB ($\overline{x} \pm S_{\overline{x}}$)	27.21±0.166^{0}C	27.32±0.170^{0}C
T_E ($\overline{x} \pm S_{\overline{x}}$)	25.67±0.224^{0}C	25.67±0.224^{0}C
N	77	77
Difference ($\overline{x} \pm S_{\overline{x}}$)	1.53±0.239^{0}C (t=6.420***)	1.65±0.252^{0}C (t=6.549***)
Correlation	0.273*	0.205*
RH_IB ($\overline{x} \pm S_{\overline{x}}$)	60.87±0.599%	60.32±0.615%
RH_E ($\overline{x} \pm S_{\overline{x}}$)	60.72±0.679%	60.72±0.679%
N	77	77
Difference ($\overline{x} \pm S_{\overline{x}}$)	0.15±0.314% (0.467^{NS})	-0.39±0.323% (-1.232^{NS})
Correlation	0.887***	0.880***
THI_IB ($\overline{x} \pm S_{\overline{x}}$)	75.83±0.253	75.89±0.254
THI_E ($\overline{x} \pm S_{\overline{x}}$)	73.78±0.321	73.78±0.321
N	77	77
Difference	2.05±0.344 (t=5.973***)	2.12±0.357 (t=5.927***)
Correlation	0.301**	0.247*

*** significant at level p<0.001
** significant at level p<0.01
* significant at level p<0.05
^{NS} non significant

The statistical model reveal that there was statistical significant differences in the minimal values for daily microclimate parameters inside the barns before and after installation of cooling equipment. In meantime, the period of year and days during the trial have significant influence on mean values for wether data. However, the interaction of cooling systems, months and days of hot summer season showed statistical significant influence on the microclimate conditions inside the cow barns with exception for the maximal values for air temperature and THI. Implementation of cooling systems in dairy herds can improve milk performance of lactating Holstein cows, and lessen the severity of heat stress during summer months. In this trial, average daily THI measurements inside the cow barns ranged between 69.90 and 79.60 and were above a threshold level 68 of THI considering to represents mild to moderate heat stress (Zimbelman et al., 2009). Previous studies has demonstrated the negative effects of heat stress on milk production start at a THI of 55 and are more evident at higher THI and high ambient air temperature (Garcia-Ispierto et al., 2006; Trajchev et al., 2016). The high temperature and humidity of the environment restrict the passing of the heat from the surface of the body, which can lead to a retrograde heat flow. Thermal stress enforced by high ambient temperatures may be alleviated by using forced ventilation and evaporation of water, which may be attained using cooling systems based on spray and fans. The results from the present research indicating that ambient air temperature and THI were higher inside the barn compared with the official meteorological station during hot climate conditions. These results are in agreement with Schuller et al. (2013), who found that temperature, RH, and THI were all consistently higher within the barn microclimate compared with official meteorological stations. A variety of factors could influence the microclimate within the barn environment and explain why they might differ from meteorological station conditions. Some structural considerations that affect the internal environment of a barn and that were not assessed in the current study include barn orientation relative to prevailing winds, presence of foliage surrounding the structure, elevation, barn width, roof slope, and roof type and insulation (Shoshani and Hetzroni, 2013). Higher air temperature in the barn during summer months may be a result of a poor ventilation and heat congestion usually caused by structural deficiencies or insufficient use of fans and sprinklers (Collier et al., 2006). Literature data reported that evaporative cooling can improve the environment of dairy cows better than using just the system of fans (Collier et al., 2006).

Table 2. Multivariate GLM for influence of cooling system and hot season of year on average daily, minimal and maximal values of weather data

Fixed variables	df	T_Ib[a]	T_Ibmin[b]	T_Ibmax[c]	RH_Ib[d]	RH_Ibmin[e]	RH_Ibmax[f]	THI_Ib[g]	THI_Ibmin[h]	THI_Ibmax[i]
Model	139	9070,368***	2354,896***	612,732***	1220,029***	283,815***	1692,408***	77495,389***	22415,215***	1885,3511***
Cooling system (C_S)	1	2,091	21,863***	,070	,905	24,334***	,001	,935	11,507**	,048
Months in year (M_Y)	1	307,384***	111,978***	14,9256**	9,467**	,632	1,114	569,347***	196,046***	13,497**
Days in months (D_M)	30	27,49***	15,257***	2,293*	7,064***	5,804***	5,954***	64,312***	31,069***	2,401*
Interaction C_S x M_Y x D_M	105	21,019***	10,826***	1,895	9,867***	6,079***	6,594***	54,471***	25,310***	2,062
Error	15									
Total	154									
[a]R^2=1.000; [b]R^2=1.000; [c]R^2=0.998; [d]R^2=0.999; [e]R^2=0.996; [f]R^2=0.999; [g]R^2=1.000; [h]R^2=1.000; [i]R^2=0.999;										

*** significant at level p<0.001
** significant at level p<0.01
* significant at level p<0.05

A large droplet from a low-pressure sprinkler system that completely wets the cow by soaking through the hair coat to the skin is more effective than a misting system. However, the fan/sprinkler system used about 10-fold more water than did the fan/mist system. Thus, attention to water delivery rate through nozzle size or the use of fans and misters has proven effective in cooling cows, and used substantially less water than systems evaluated in earlier research. Evaporative water loss of up to 1.5 kg/h of dairy cows (Berman et al., 1985), on top of poor ventilation, might contribute to the high RH inside the barn during summer months. Specifically, Armstrong et al. (1999) reported that cows housed under feed-line spray and fan systems had a lower percentage increase in respiration rate for feed line spray systems closest to the cow. In addition to cooling systems, they reported that free stalls should be constructed to provide good natural ventilation. The ridge opening should be 5 cm for each 3 m of free-stall building width. Most free-stall cooling trials have been more successful at cooling the cows in the feed-line area using spraying fans and misters than cooling the cow in the bedded stall. Although there are some concerns about re-radiation under corrugated iron roofs when the amount of heat from the re-radiation will be far less than if the animal were to have received it from a direct solar heat load (Knogdee et al., 2006). Evaporative cooling systems have improved the environment for lactating dairy cows in hot climates. These systems use high pressure, fine mist, and large volumes of air to evaporate moisture and cool the air surrounding the cow. There are questions regarding the effectiveness of evaporative systems in climates with high relative humidity because when relative humidity increases above 70%, the potential reduction in THI is less than 10%. Our results highlight the fact that time of cooling as management practice for reducing the negative effect of heat stress in dairy cows should be prolonged in whole period of environmental heat stress.

Conclusions

The installed equipment in the barns of the farm 1 included one fan and three fans plus fogging system in the farm 2. Due to farm specific and unpredictable variability in climate conditions inside the cow barns and their correlation with environmental weather data, the installed cooling systems could provide better climate zone in the barns neccesssery for increased milk production but couldn't completely satisfy capacity of cooling during the day time with highest air temperature and air relative humidity and therefore highest THI. It is planning in the near future to install one more fan in the farm1 and farm 2 in order to completely satisfy capacity of ventilation and cooling.

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References

1. Armstrong, D.V., Hillman, P.E., Meyer, M.J., Smith, J.F. and Stokes, S.R. (1999). Heat stress management in freestall barns in the western US. Proceedings of the Western Dairy Management Conference, Las Vegas, NV.
2. Berman, A., Folman, Y., Kaim, M., Mamen, M., Herz, Z., Wolfenson, D., Arieli, A. and Graber, Y. (1985). Upper critical temperatures and forced ventilation effects for high-yielding dairy cows in a subtropical climate. J. Dairy Sci. 68: 1488–1495.
3. Berman, A. (2009). Predicted limits for evaporative cooling in heat stress relief of cattle in warm conditions. J. Anim. Sci. 87: 3413–3417.
4. Bohmanova, J., Misztal, I., Cole. J.B. (2007). Temperature-humidity indices as indicators of milk production losses due to heat stress. J. Dairy Sci. 90:1947-1956.
5. Collier, R.J., Dahl, G.E., VanBaale, M.J. (2006). Major advances associated with environmental effects on dairy cattle. J Dairy Sci, 89: 1244-1253.

6. Garcia-Ispierto, I., Lopez-Gatius, F., Santolaria, P., Yaniz, J.L., Nogareda, C., Lopez-Bejar, M. and De Rensis, F. (2006). Relationship between heat stress during the peri-implantation period and early fetal loss in dairy cattle. Theriogenology 65: 799–807.
7. Kadzere, C.T., Murphy, M.R., Silanikove, N., Maltz, E. (2002). Heat stress in lactating dairy cows: a review. Livest Prod Sci, 77: **59**-91.
8. Khongdee, S., Chaiyabutr, N., Hinch, G., Markvichitr, K. and Vajrabukka, C. (2006). Effects of evaporative cooling on reproductive performance and milk production of dairy cows in hot wet conditions. International Journal of Biometeorology, **50**:30.
9. Rhoads, M.L., Rhoads, R.P., VanBaale, M.J., Collier, R.J., Sanders, S.R., Weber, W.J., Crooker, B.A., Baumgard, L.H. (2009). Effects of heat stress and plane of nutrition on lactating Holstein cows: I. Production, metabolism, and aspects of circulating somatotropin. J. Dairy Sci. 92:1986-1997.
10. Schuller, L.K., Burfeind, O. and Heuwieser. W. (2013). Short communication: Comparison of ambient temperature, relative humidity, and temperature-humidity index between on-farm measurements and official meteorological data. J. Dairy Sci. 96: 7731–7738.
11. Shoshani, E. and Hetzroni, A. (2013). Optimal barn characteristics for high-yielding Holstein cows as derived by a new heat-stress model. Animal 7: 176–182.
12. Silanikove, N. (2000). Effects of heat stress on the welfare of extensively managed domestic ruminants. Livest Prod Sci, 67: 1-18.
13. Trajchev, M., Nakov, D., Andonov, S. (2016). The effect of thermal environment on daily milk yield of dairy cows. Mac Vet Rev, Vol. 39(2), pg. 185-192.
14. Winsten, J.R., Kerchner, C.D., Richardson, A., Lichau, A. and Hyman, J.M. (2010). Trends in the northeast dairy industry: Large-scale modern confinement feeding and management-intensive grazing. J. Dairy Sci. 93:1759–1769.
15. Zimbleman, R.B., Rhoads, R.P., Rhoads, M.L., Duff, G.C., Baumgard, L.H. and Collier, R.J. (2009). A re-evaluation of the impact of temperature humidity index (THI) and black globe humidity index (BGHI) on milk production in high producing dairy cows. Pages 158–168 in 24th Annu. Southwest Nutrition Management Conf., Temple, AZ. University of Arizona, Tucson.