Research on the determination of heat and water vapor emissions of Anatolian water buffaloes under indoor environmental conditions

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Abstract: This study was carried out to determine the amount of total heat, sensible heat, latent heat, and water vapor emitted by Anatolian water buffaloes in a closed barn located in the Thrace region of Turkey. At the research farm, a group was formed by randomly selecting water buffaloes based on their genetic similarities and lactation numbers. The buffalo group formed was housed in a closed-type barn. The inside and outside air temperatures, relative humidity, and milk yield values of the buffaloes were recorded for 1 year. According to the results of this research, the Anatolian water buffaloes emitted 653 kcal/h AU sensible heat, 351 kcal/h AU latent heat, and 518 g/h AU water vapor during the winter, while they emitted 421 kcal/h AU sensible heat, 536 kcal/h AU latent heat, and 916 g/h AU water vapor during the summer in the barn environment under optimum design conditions. These values can be used to control indoor climatic environmental conditions, design ventilation systems, select structural properties, and determine insulation requirement in terms of animal welfare.

Key words: Anatolian water buffalo, animal welfare, sensible heat, latent heat, water vapor

1. Introduction

It is possible to increase the economic income gained from livestock by improving the genotype and keeping environmental conditions at appropriate levels within economic limits. Farm animals emit heat and water vapor into the barn environment. The amount of heat and water vapor emitted by water buffaloes varies depending on the indoor temperature/humidity values, housing, feeding, and water systems.

Although there are large changes in the ambient temperature, farm animals are able to keep their body temperature stable within very narrow limits. The normal body temperatures of farm animals vary between approximately 37 and 41.7 °C, depending on the species and breeding method [1]. Maintaining their body temperature within the suggested limits is possible for animals by maintaining a balance between heat generation and heat convection from their bodies. Metabolic heat production increases under cold climatic conditions, whereas heat loss remains at low levels. In hot climatic conditions, metabolic heat production decreases and latent heat emission increases [2]. When the body temperature and indoor air temperature are higher than the internal surface temperature of building elements surrounding the indoor air, there is continuous heat loss from the body

to the outdoor environment in the winter and transition seasons. For summer, a continuous heat load occurs from the outdoor environment to the animal [3].

Generally, in calculating the heat/humidity balance in animal production structures, the amount of heat, latent heat, and water vapor emitted by animals are taken as a basis. The heating process is not performed unless it is required. If there is a heat gap, first of all, this should be covered by the insulation of building elements. On the other hand, in designing ventilation systems in the barns, it is aimed to determine the minimum and maximum capacity of the system based on sensible heat for summer conditions and latent heat or water vapor for winter and transition seasons [4]. The design temperature and relative humidity values for a region should be carefully determined in order to provide a suitable balance between the structure economy and thermal stress conditions.

This study was carried out at a farm located in the Thrace region of Turkey. All of the Anatolian water buffaloes grown in this region are Mediterranean buffaloes and originated from river buffaloes [5]. In this region, the natural habitats of water buffaloes have gradually been shrinking due to various reasons, which may cause a transition from the pastoral livestock system to the barn system. However, the climatic environment should be

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controlled within economic limits in closed-type barns and the amount of heat and water vapor emitted by water buffaloes into the indoor environment should be known in order to keep animal welfare in the comfort zone. The purpose of this study was to determine the amount of heat and water vapor emitted by Anatolian water buffaloes into the indoor environment under the existing and optimum conditions.

2. Materials and methods

This study was conducted at a water buffalo farm that had a sufficient herd capacity. The farm, a member of the Water Buffalo Breeder Association, is located in the Thrace Part of İstanbul Province, at 41°12′ N, 28°44′ E and at an average altitude of 119 m. According to meteorological records, the average annual temperature of the study area is 13.8 °C and the average annual relative humidity is 84.5% [6].

A total of 24 Anatolian water buffaloes were housed in the investigated barn and their average live weight was 537.25 kg. The required calculations were implemented based on the number of 28.4 animal units (AU) and this value was determined based on 454 kg of body weight. In order to control the indoor air temperature, a fogging system was installed. It was aimed to keep the indoor air temperature close to 25 °C, which was accepted as initial heat stress. The temperature and relative humidity values of the indoor and outdoor air were continuously measured at 10-min intervals for 1 year using the thermohygrometers installed inside and outside the barn. In addition, the daily milk yield records of the Anatolian water buffaloes were also monitored.

The heat-humidity balance for the control of climatic environment in animal barns is generally calculated based on the total heat, sensible heat, latent heat, and water vapor values emitted by animals into the indoor environment. These values were calculated using the equations proposed by the CIGR [7], Pedersen [8], and Mutaf [3] for bovine animals, as given below.

The amount of total heat (for an indoor temperature of 20 °C):

$$q_T = (5.6 \times m^{0.75} + 22 \times Y + 1.6 \times 10^{-5} \times P^3) \times 0.86. \quad (1)$$

The amount of fixed total heat used for conditions where the indoor dry bulb temperature is below or above 20 °C:

$$q_{T.cor} = q_T \times t_{cor.fac} \quad (2)$$

The correction factor (when the indoor temperature was between 0 and 30 °C):

$$T_{cor.fac} = [1 + 4 \times 10^{-3}(20 - t_{db})]. \quad (3)$$

The amount of sensible heat:

$$q_{sen} = q_{T.cor} \times [(0.71 \times t_{cor.fac}) - (0.407 \times 10^{-3} \times t_{db}^2)]. \quad (4)$$

The amount of latent heat:

$$q_{lat} = q_{T.cor} - q_{sen}. \quad (5)$$

The amount of water vapor:

$$w_{ani} = q_{lat} \div 0.5848. \quad (6)$$

Here, q_T is the amount of total heat (kcal/h), m is the live weight (kg), Y is the daily milk yield (kg/day), P is the gestation period (day), t_{db} is the dry bulb temperature (°C), $q_{T.fix}$ is the amount of fixed total heat (kcal/h), $t_{fix.fac}$ is the fixing factor, q_{duy} is the amount of sensible heat (kcal/h), q_{giz} is the amount of latent heat (kcal/h), w_{hay} is the amount of water vapor emitted by transpiration and respiration of the animals (g/h), and the value 0.5848 is the evaporation heat of water (kcal/g).

3. Results

The control of indoor environmental conditions can be achieved by keeping the indoor temperature and relative humidity within appropriate limits for animals and providing sufficient air flow into the barn. It is particularly important to determine the temperature and relative humidity values of the indoor and outdoor air in closed-type animal barns. The daily average temperature and relative humidity values were calculated using the data recorded. The daily average values of the indoor temperature for different seasons are given in Figure 1.

As seen in Figure 1, the minimum and maximum average values of the indoor temperature were 10.5 and 17.8 °C in the winter, and 20.0 and 26.8 °C in the summer. The average indoor temperature was not stressful for animal welfare in either critical season. Particularly in the summer, the indoor temperature was controlled using a fogging system and it was kept close to 25 °C, which was considered as the intial point of heat stress. The daily average values of the outdoor temperature for the different seasons are given in Figure 2.

When Figure 2 is examined, it can be seen that the minimum and maximum average values of the outdoor temperature were –1.4 and 17.7 °C in the winter, and 18.0 and 28.3 °C in the summer.

The daily average values of the indoor relative humidity are shown in Figure 3.

When Figure 3 is examined, it can be seen that the minimum and maximum average values of the indoor relative humidity were 58.6% and 81.3% in the winter, and 60.4% and 80.5% in the summer. These relative humidity values did not pose a problem in terms of animal welfare. The daily average values of the outdoor relative humidity for different seasons are given in Figure 4.

The minimum and maximum average values of the outdoor relative humidity were 58.6% and 81.3% in the winter, and 60.4% and 80.5% in the summer.

The relative humidity values at the investigated farm were not considered to pose any problem in terms of animal welfare. When calculating the heat-moisture balance in closed-type barns, it is necessary to have information about the total heat, sensible heat, latent heat, and water vapor emitted by the animals into the indoor environment.
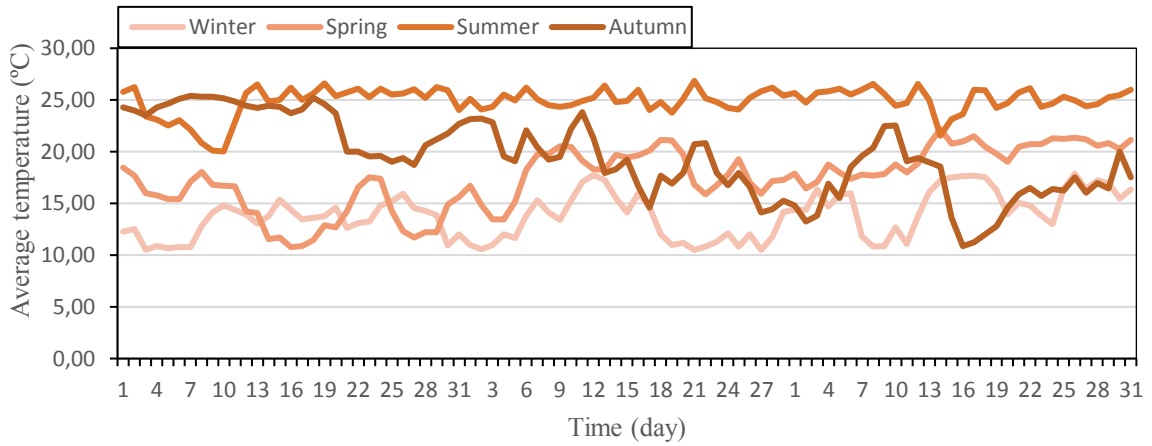
Figure 1. Daily average values of the indoor temperature for the different seasons.
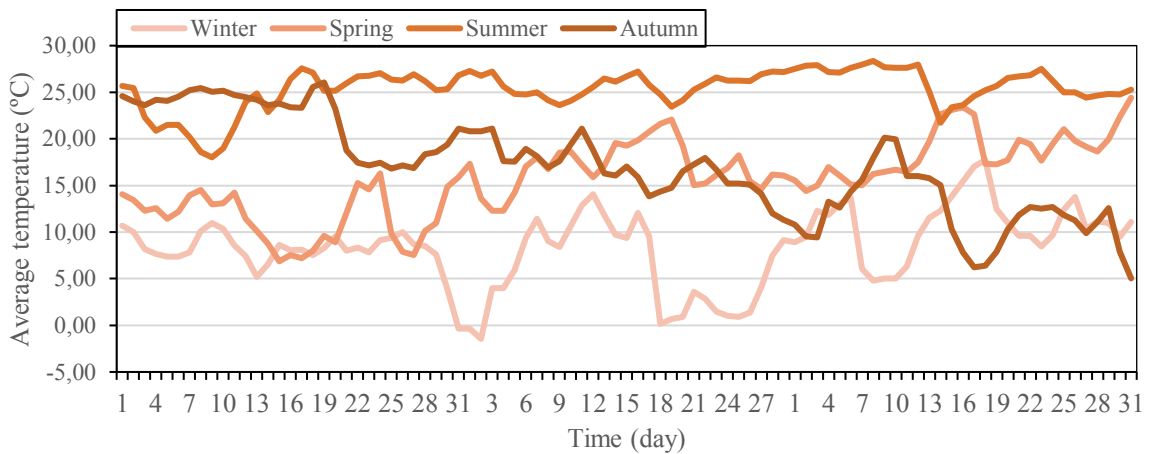

Figure 2. Daily average values of the outdoor temperature for the different seasons.
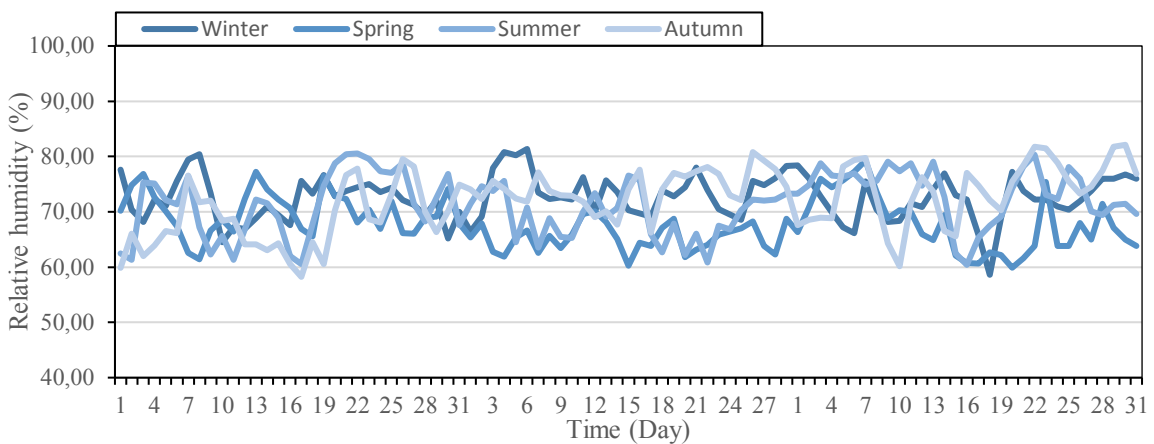

Figure 3. Daily average values of the indoor relative humidity for the different seasons.

For this purpose, being considered as critical values, the minimum and maximum daily temperature averages were determined for the different seasons using the temperature data recorded in the study. The equations and principles proposed by the CIGR [7], Pedersen [8], and Mutaf [3] were used to calculate the amount of heat and water
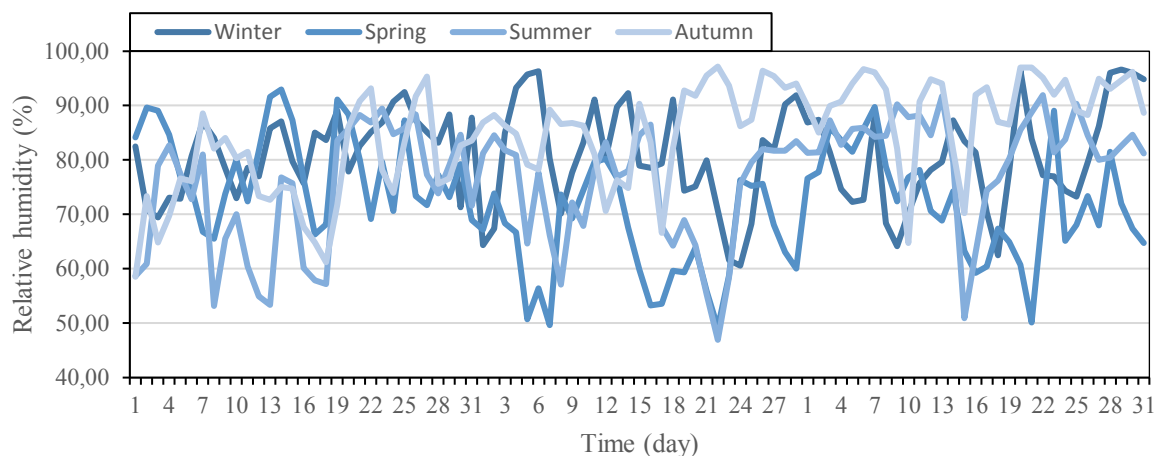
Figure 4. Daily average values of the outdoor relative humidity for the different seasons.

vapor emitted by the Anatolian buffaloes into the indoor environment. The data used in the calculations are given in Table 1, and the amount of heat and water vapor emitted by the buffaloes into the indoor environment are given in Table 2.

As seen in Table 2, the amount of heat and water vapor emitted by the water buffaloes varied depending on the indoor temperature. On the other hand, when the indoor temperature decreased, the amount of sensible heat emission increased, and the amount of latent heat and water vapor emission decreased. Furthermore, when the indoor temperature increased, the amount of latent heat and water vapor emission increased, and the amount of sensible heat emission decreased.

In the planning of animal barns, it is necessary to provide an appropriate and economic balance between the indoor and outdoor environment conditions of the region. Therefore, the determination of climatic project criteria for the indoor and outdoor air is one of the most important issues to provide optimum conditions for the indoor environment, calculate the balance between heat and humidity, and determine economic construction for the building. For this purpose, the temperature and relative humidity project criteria were determined for different seasons in accordance with the principles stated by Ekmekyapar [9] and Mutaf [3]. The data used to calculate the heat-humidity balance are given in Table 3.

The total heat, sensible heat, latent heat, and water vapor values emitted by the buffaloes under different seasonal conditions were calculated per AU, and presented in Table 4 using the optimum project criteria given in Table 3.

When Table 4 is examined, it can be seen that while the buffaloes emitted 653 kcal/h sensible heat, 351 kcal/h latent heat, and 518 g/h per AU water vapor in the winter, they emitted 421 kcal/h sensible heat, 536 kcal/h latent

heat ,and 916 g/h water vapor per AU in the summer, based on the optimum design conditions. These values can be used to control the climatic environment in closed-type water buffalo barns at optimum levels using the humidity balance in the winter and heat balance in the summer.

4. Discussion

In this study, The minimum and maximum average values of the indoor temperature were 10.5 and 17.8 °C in the winter, 20.0 and 26.8 °C in the summer. The values measured in the research barn for the winter were close to the accepted comfort temperature values for livestock and they were at a level that did not pose a problem in terms of animal welfare and yield. In the summer, the indoor temperature could be kept close to 25 °C, which was accepted as the temperature at which temperature stress starts in the fogging system. In fact, Mutaf [3] asserted that the temperature at which heat stress starts in farm animals was 25 °C. Similarly, Wathes and Charles [10], and Ekmekyapar [9], claimed that the appropriate temperature limits for farm animals were between 4 and 25 °C.

The effects of relative humidity on animals should be considered together with the temperature. It is recommended that the relative humidity value should be between 40% and 80% for appropriate temperature limits. The relative humidity should never be less than 30% or more than 90% [3,11]. The minimum and maximum relative humidity values measured in the research barn were 58.6% and 81.3% in the winter, and 60.4% and 80.5% in the summer, respectively. These values were within the proposed range for animal welfare. Indeed, Maton et al. [12] and Olgun [13] reported that the indoor relative humidity for bovine animals should be between 55% and 80% at optimum temperature conditions, and the relative humidity may be allowed to rise up to 85% in order to economically control the climatic environment during cold

Table 1. Obtained data used to calculate the amount of heat and humidity.

Season	Critical value	Indoor temperature t_i (°C)	Indoor relative humidity (%)	Outdoor temperature t_d (°C)	Outdoor relative humidity ϕ_d (%)	Live weight AU (kg)	Average gestation period P (day)	Daily milk yield Y (kg)
Winter	Min.	10.5	69.2	−1.45	67.4	454	310	9
	Max.	17.8	71.9	13.8	78.5	454	310	8.0
Spring	Min.	10.7	70.6	7.5	76.4	454	310	8.0
	Max.	21.5	67.9	19.8	73.3	454	310	7.0
Summer	Min.	20.0	70.3	16.8	68.4	454	310	5.5
	Max.	26.8	68.7	25.3	65.2	454	310	6.0
Autumn	Min.	11.3	74.8	6.2	78.3	454	310	5.0
	Max.	25.4	71.7	23.6	80.2	454	310	5.5

Table 2. Amount of heat and water emitted into the indoor environment per AU under critical conditions.

Season	Critical value	Indoor temperature t_i (°C)	Total heat q_T (kcal/h)	Correction factor $t_{cor.fac}$	Corrected total heat $q_{T.cor}$ (kcal/h)	Sensible heat q_{sen} (kcal/h)	Latent heat q_{lat} (kcal/h)	Water vapor W_{ani} (g/h)
Winter	Min.	10.5	1053.5	1.038	1093.5	756.8	336.7	575.7
	Max.	17.8	1034.6	1.008	1042.8	610.9	431.9	738.5
Spring	Min.	10.7	1034.6	1.037	1072.8	740.2	332.6	568.8
	Max.	21.5	1015.7	0.994	1009.6	521.8	487.8	834.1
Summer	Min.	20.0	987.3	1.000	987.3	540.2	447.1	764.4
	Max.	26.8	996.7	0.969	965.8	364.8	601.0	1027.7
Autumn	Min.	11.3	977.8	1.035	1011.9	691.4	320.5	548.0
	Max.	25.4	987.3	0.978	965.5	417.1	548.4	937.7

Table 3. Optimum project criteria used to calculate the heat-humidity balance.

Season	Indoor project temperature t_i (°C)	Indoor project relative humidity ϕ_i (%)	Outdoor project temperature t_o (°C)	Outdoor project relative humidity ϕ_d (%)	Live weight of water buffalo (kg)	Average gestation period of water buffalo (day)	Minimum daily milk yield (kg)
Winter	13	75	−1	95	454	310	5
Spring	18	75	10	85	454	310	5
Summer	25	80	26.6	84.1	454	310	5
Autumn	18	75	10.0	85.1	454	310	5

Table 4. Amount of heat and water emitted into the indoor environment per AU under optimum conditions.

Season	Total heat (kcal/h)	Correction factor	Corrected total heat (kcal/h)	Sensible heat (kcal/h)	Latent heat (kcal/h)	Water vapor (g/h)
Winter	977	1.028	1004	653	351	518
Spring	977	1.008	985	574	411	604
Summer	977	0.98	957	421	536	916
Autumn	977	1.008	985	574	411	604

periods. The amount of heat and water vapor produced by the animals in the barn varied depending on the degree of temperature and humidity in the indoor environment. For this reason, when the thermal environment control in a barn is insufficient, effective utilization of the genotypic potential decreases as a result of the negative effect of heat stress, which causes a loss in yield [14]. Therefore, the amount of heat and water vapor emitted by the buffaloes under the existing and optimum conditions were calculated according to the AU. In the literature, no research has been carried out on the heat and water vapor emitted by Anatolian water buffaloes. The data obtained from the study will contribute to filling this gap, because this type of data is required for determining the size of ventilation systems, which are effective in controlling the climatic environment in closed-type shelters, and calculating the insulation requirement of the building elements.

5. Conclusion

Considering the physiological and genetic characteristics of the water buffaloes, the indoor temperature and relative humidity had a significant effect on the milk yields.

Extreme conditions negatively affected the amount of milk. Specifically when regulating the climatic environmental conditions for closed-type barns, the amount of heat and water vapor emitted by the animals into the indoor environment should be known. In this study, the amount of heat and water vapor emitted by the Anatolian water buffaloes into the barn environment was calculated for the existing and optimum conditions. According to this, while the Anatolian water buffaloes emitted 653 kcal/h sensible heat, 351 kcal/h latent heat, and 518 g/h water vapor per AU in the winter, they emitted 421 kcal/h sensible heat, 536 kcal/h latent heat, and 916 g/h water vapor per AU in the summer. It is suggested that these values should be considered in order to control indoor climatic conditions, design ventilation systems, select structural properties, and determine insulation requirements.

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