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Research Article

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A Research on Determination of Ventilation Capacity for Heat-Humidity and CO_2 Balance in Closed Type Water Buffalo Barn

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Abstract This study was carried out to determine the ventilation capacity according to different seasons for the current situation and optimum conditions of closed type water buffalo barns. Two water buffalo groups were formed; one of the groups was housed in the Barn-I where the indoor temperature was controlled and the fogging system was installed, and the other group was housed in the Barn-II under existing farmer conditions. In the result of this research, the required ventilation capacities for heat, humidity and gas balance were calculated. The required ventilation capacities for CO_2 and humidity balance in the both barns were calculated as 97.1 m^3 / h BHB and 110.4 m^3 / h AU respectively, in the optimum barn conditions. For the heat balance, the required ventilation capacity was 385.5 m^3 / h AU in the Barn-I due to the efficiency of the fogging system and this value was calculated as 392.1 m^3 / h AU in the Barn-II.

Keywords Water buffalo barn, ventilation, heat-humidity balance, CO_2 balance

Introduction

The main purpose is to gain the highest economic efficiency in the commercial animal breeding. Sufficient feeding, proper genotype and balanced environment conditions of animal barns should be considered [1]. The planning and construction of barns has great importance because feeding animals have great economic value and obtained products are closely related to human health [2].

Farm animals want to live under proper temperature and humidity conditions. For this reason, one of the most important factors in utilization of the genotypic potential of animals is indoor climatic conditions. The thermal conditions of the outdoor environment are mostly incompatible with the thermal conditions that are required by farm animals. Providing suitable thermal conditions can be possible by keeping some variables such as temperature and humidity at suggested levels [3]. The desired temperature and humidity conditions in different seasons and elimination of the harmful gases in barn environment can be provided by well-planned ventilation systems. Different methods are used to determine the ventilation capacity. The fundamental of these methods is based on heat balance, humidity balance and gas balance [4].

In our country, water buffaloes and other cattle breeds are considered in the same category but there are important difference between them based on the genetics and physiological characteristics. So, the studies that insist on controlling of climate conditions in water buffalo barns should be performed.

This study was carried out to determine the ventilation capacity according to different seasons for the current situation and optimum conditions of closed type water buffalo barns in Istanbul Province where is located in Thrace part of Turkey.

Material and Method

This study was carried out in a water buffalo farm located in Thrace Part of Istanbul Province and a member of Water Buffalo Breeder Assocation. This farm was selected based on barn type and structural characteristics which had the ability to represent the other buffalo farms in the region.The study area is geographically located in 41° 12' northern latitude and 28 ° 44' east longitude and at 119 m altitude[5].

Two group water buffaloes were housed in two closed type barns. One of the groups was housed in the Barn-I where the indoor temperature was controlled and the fogging system was installed, and the other group was housed in the Barn-II under existing farmer conditions. The indoor temperature was kept below 25 ° C, which is considered to be the initial temperature value of heat stress in the Barn- I. Same feeding rations were implemented for each group. The temperature, humidity and CO_2 measurements of indoor and outdoor environments were recorded at intervals of 10 minutes for one year.

The capacity of the ventilation system for different seasons has been calculated with the help of the equations given below based on the balance of heat, humidity and CO_2 [4-6].

Heat Balance:

$$G_{heat} = (q_{sensible.} - q_{building.}) / (h_0 - h_1) \quad (1)$$

In the equation;

where G_{heat} is required ventilation capacity for summer season (kg/h),$q_{sensible}$ is amount of sensible heat emitted by animals into indoor environment in summer season project condition (kcal/h), $q_{building}$ is amount of heat loss through the building elements (kcal/h),h_0 is enthalpy of the air thrown from the shelter with indoor temperature and specific humidity of the air which are taken from outdoor into indoor (kcal/kg) and h_1 is enthalpy of outside air in project conditions (kcal/kg).

Humidity balance:

$$G_{humidity} = q_{latent.} / (h_2 - h_0) \quad (2)$$

or

$$G_{hıumidity} = w_{animal.} / (w_2 - w_1) \quad (3)$$

In the equations;

Where $G_{humidity}$ is required ventilation capacity for summer season (kg/h), q_{latent} is amount of sensible heat emitted by animals into indoor environment in summer season project condition (kcal/h), h_2 is enthalpy of indoor air in project condition(kcal/kg), $w_{animal.}$ is amount of water vapor emitted by animals into indoor environment in summer season project condition (g/h), w_2 is specific humidity of indoor air in winter season conditions (g/kg) and w_1 is specific humidity of outdoor air in winter season conditions (g/kg).

CO_2 balance:

$$Q_{CO2} = [(q_{T.fixed} \text{ x } 0.185\text{x}10^{-3})]10^6 / [(m_{iCO2} - m_{oCO2})/1.29] \text{ x p} \quad (4)$$

In equation;

where Q_{CO2} is minimum ventilation capacity for CO_2 balance (m^3/h $kg_{liveweight}$), $q_{T.fixed}$ is fixed total heat amount dispersed to the indoor environment considering ambient temperature (W/$kg_{liveweight.}$), m_{iCO2} is CO_2value of indoor air (ppm), m_{oCO2} is CO_2value of outdoor air (ppm), and p is specific mass of air (kg/m^3).

Results and Discussion

In order to keep the climatic environment within optimum or near optimum limits with regard to animal welfare in closed type animal production structures, firstly ventilation systems are used and the flow rate of the ventilation system is determined according to different approaches.It gives the capacity of the system which is higher the calculated flow rate and ventilation systems are sized according to this value.

The floor area and internal volume amounts per water buffalo were 3.41 m^2 and 12.03 m^3, respectively in the Barn-I. Also , these values were 3.27 m^2 and 12.25 m^3, respectively in the Barn-II. In order to provide homogeneity in the calculations, AU (Animal Unit) which is equal to 454 kg (1000 Pound) of the live weightwas used. The average live weight of Anatolian water buffaloes in the research farm was 537.25 kg. On the basis of this value, 28.4 AU were housed inthe Barn-I and 17.7 AU were housed in the Barn-II. Critical values were taken into account as project criteria in the used calculations for different seasons and these values were given in Table 1.

Table 1: Project criteria were used in heat-humitidy calculations for different seasons

Season	Indoor temper. (°C)	Indoor humidity (%)	Outdoort emper. (°C)	Outdoor relative humidity (%)	Water Buffalo live weight (kg)	Average gestitaton period of Water Buffalo (day)	Daily minimum 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

The total heat, sensible heat, latent heat and water vapor values released by water buffaloes in different seasons conditions were calculated in Table 2 with the help of the principles and equations given in CIGR [6], Pedersen [7] and Mutaf [3].

Table 2: Amountsof heat and water vapor emitted by water buffaloes per AU

Season	Sensible heat (Kcal/h)	Latent heat (Kcal/h)	Water vapor content (g/h)
Winter	653	351	518
Spring	574	411	604
Summer	421	536	916
Autumn	574	411	604

Considering the climatic conditions of the region where the research were carried out, heat accumulation problem for winter season is not even a matter in the barns. The main problem for winter season is that throwing out excess moisture and harmful gases which accumulated in the barn environment depending on the rate of occurrence. In spring and autumn seasons, for some cases, humidity is a problem in closed barns and also heat accumulation can be a problem. In the summer months, the indoor temperature rises above the optimum values very much due to low heat loss from building elements in the closed type animal barn andheat flow from the external atmosphere to barn environment for some cases. In the summer, however, humidity is usually not a problem. The problem is the removal of excess heat accumulated in the barn environment. Therefore, when planning ventilation systems for the summer months, heat balance should be taken as a basis [4].

While determining the capacity of the natural ventilation systems in the current situation, the air outlet chimney sections used in the ventilation and the air velocity average values measured by the hand anemometer were used.

The psychrometric diagram, equations and principles given in Ekmekyapar [4], Okuroğlu and Yağanoğlu [8], Olgun [9] and Mutaf [3]wereused in the heat and humidity calculations according to the project criteria given in Table 1 and Table 2.

The ventilation capacities for CO_2 balance were calculated based on measured CO_2 concentrationsin the barns during the research, the recommended upper limit value for animal production structures (3000 ppm) and the maximum CO2 concentrations measured in the outdoor environment for different seasons. Accordingly, the maximum value ofmeasured CO_2 concentrations in the outdoor air was 599.00 ppm for winter, 562.50 ppm for spring months, 474.31 ppm for summer months and 586.86 ppm for autumn months. The calculated ventilation capacities according to different approaches for winter conditions were given in Table 3.

Table 3: The calculated ventilation capacities according to different approaches for winter conditions

Barn number	Amounts of the ventilation capacity calculated by different method					
	Existing system (m^3/h)		Humidity balance (m^3/h)		CO_2 balance (m^3/h)	
	Total	Per AU	Total	Per AU	Total	Per AU
Barn-I	3366	118.5	3136	110.4	2757	97.1
Barn-II	1620	91.5	1954	110.4	1718	97.1

According to Table 3, it was seen that there was no problem in Barn-I with regard to ventilation capacity, the existing ventilation capacity were calculated as 91.5 m^3/hin Barn-II. The value did not meet the requirement of ventilation capacity for humidity balance (110.4 m^3/h). This situation causedhigh relative humidity values which were above the optimum values in the barn. In the same way, it was seen that the ventilation capacity in the current situation was below the ventilation capacity for the harmful gas balance (97.3 m^3/h).

The calculated ventilation capacities according to different approaches for spring conditions were given in Table 4.

Table 4: The calculated ventilation capacities according to different approaches for spring conditions

Barn number	Amounts of the ventilation capacity calculated by different method					
	Existing system (m^3/h)		Humidity balance (m^3/h)		CO_2 balance (m^3/h)	
	Total	Per AU	Total	Per AU	Total	Per AU
Barn-I	4320	152.1	5023	176.8	2714	95.6
Barn-II	2592	146.4	3130	176.8	1692	95.6

According to Table 4, although the amount of ventilation in the current situation was sufficient in terms of the harmful gas balance, it was seen that both of the barnswere not sufficient to maintain the heat balance under optimum conditions. Especially in theBarn-II, the temperature of the indoor environment were 4-6 °C higher than optimum indoor temperature (18 °C). But this difference does not cause any heat stress for farm animal welfare.

The calculated ventilation capacities according to different approaches for summer conditions were given in Table 5.

Table 5: The calculated ventilation capacities according to different approaches for summer conditions

Barn number	Amounts of the ventilation capacity calculated by different method					
	Existing system (m^3/h)		Humidity balance (m^3/h)		CO_2 balance (m^3/h)	
	Total	Per AU	Total	Per AU	Total	Per AU
Barn-I	11232	395.5	10948	385.5	2614	92
Barn-II	6804	384.4	6939	392.1	1629	92

According to Table 5, it was seen that there was no problem in the Barn-I in terms of ventilation capacity, while the current ventilation capacity in the Barn-II was less than the required ventilation capacity for heat balance when the projecttemperature was taken as 28 ^oC for summer season conditions.However, ifthe project temperature was taken as 25 ^oC which is initial temperature value of heat stress, it would be not possible to bring the indoor temperature to this value with the ventilation according to the heat balance in both barns. For this, additional precautions should be taken in order to bring the temperature value of the indoor environment to 25 ^oC. While the indoor temperature was brought closer to the optimum values with the fogging system applied in the Barn-I under the controlled conditions, the temperature exceeded 30 ^oC from time to time in Barn-II where the fogging system was not applied at the farmer conditions. In the summer season, the ventilation systems of both barns were sufficient for harmful gas balance.

The calculated ventilation capacities according to different approaches for autumn conditions were given in Table 6.

Table 6: The calculated ventilation capacities according to different approaches for autumn conditions

Barn number	Amounts of the ventilation capacity calculated by different method					
	Existing system (m^3/h)		Humidity balance (m^3/h)		CO_2 balance (m^3/h)	
	Total	Per AU	Total	Per AU	Total	Per AU
Barn-I	4860	171.1	5023	176.8	2493	87.8
Barn-II	2880	162.7	3130	176.8	1554	87.8

When Table 6 was examined, it was seen that the ventilation capacities for both barnswere sufficient in terms of harmful gas balance, but they were not enough to provide heat balance for optimum conditions in the autumn season as well as in the spring season.The indoor temperatureswere more 6-8 ^oC than 18 ^oC which is considered to be the optimum indoor temperature. It has been thought the indoor temperature values in the existing condition were not in the critical levels to make a significant temperature stress with regard to animal welfare.

Heat transfer coefficients were determined according to the equations and principles given in Balaban and Şen [10], Olgun [9] and Mutaf [3]. The amount of heat loss through the building elements were calculated by using the heat transfer coefficients for winter and spring seasons. The values of heat loss were given in Table 7.

Table 7: Heat transfer coefficients of building elements in the barns and heat loss according to heat transfer coefficient

Barn number	Building element	Area of building element (m^2)	Heat transfer coefficient of building element (Kcal/m^2 ^oC h)	Amount of heat loss by conduction in summer (Kcal/h)	Amount of heat loss by conduction in spring (Kcal/h)
	Door	3.9	2.14	115.3	65.9
	Window	4.1	3.41	180.2	111.8
I	Wall	98.0	1.84	2524.4	1442.5
	Roof	117.6	1.76	2897.6	1655.8
	Total heat loss through building element			5717.5	3276.0
	Door	4.7	2.14	141.1	80.6
	Window	2.9	3.41	142.2	81.2
II	Wall	88.0	1.93	2217.6	1267.2
	Roof	57.0	1.76	1404.5	802.5
	Total heat loss through building element			3905.4	2231.5

The calculations were made based on optimum project criteria of climatic environment detection in the researched barns and AU. The heat balance calculations for winter and spring seasons were given in Table 8.

Table 8: Heat balance calculations in the researched barns for winter and spring seasons

Season	Barn number	Heat loss through ventilation (Kcal/h)	Heat loss through building element (Kcal/h)	Total amount of sensible heat (Kcal/h)	Heat budget in the barn (Kcal/h)
Winter	I	12731.3	5717.5	18545.2	+96.4
	II	7934.4	3905.4	11558.1	-281.7
Spring	I	11652.2	3276.0	16301.6	+1373.4
	II	7262.2	2231.5	10159.8	+666.1

According to Table 8, there was a slight heat deficit in the winter conditions in the Barn-II. The heat deficit can be eliminated by increasing the freqeuncy of animals or by reducing amount of ventilation in the critical periods. In the spring months, the excess heat in the barns could be removed by arranging the air inlet and outlet openings. Generally, there were no critical heat deficit and heat excess in the both barns.

The heat balance calculations for summer and autumn seasons were given in Table 9.

Table 9: Heat balance calculations in the researched barns for summer and autumn seasons

Season	Barn number	Heat loss through ventilation (Kcal/h)	Heat loss through building element (Kcal/h)	Total amount of sensible heat (Kcal/h)	Heat budget in the barn (Kcal/h)
Summer	I	5079	654	11956	+6223
	II	3219	445	7452	+3788
Autumn	I	11652	3276	16302	+1374
	II	7262	2232	10159	+665

According to Table 9, it was seen that there were heat accumulationsfor summer months in the research barns. It was not possible to bring indoor temperature to the optimum values by the ventilation. Therefore, additional preacutions should be taken. The indoor temperature was lowered to 25 ^oC with the help of the fogging system which works based on sensible heat to latent heat conversion.

The occurring heatexcesses of researched barns could be eleminated by arranging the air inlet and outlet openings. In generally, it couldhave been said that heat excesses for both barns were not at critical levels.

Conclusion

The heat, humidity, bad odor and gases emitted by animals into the shelter must be thrown out from the barns without reaching the critical level that could be harmful to the animals. This condition can be ensured by an air exchange between the indoor and outdoor environments within certain limits. In the climatic conditions, the ventilation capacity for the humidity balance provides the minimum capacity of the ventilation systems and the ventilation for the heat balance gives the maximum capacity of the ventilation systems. The required ventilation capacity for CO_2 balance is lower than the required capacity for the heat-moisture balance. When the ventilation systems in the research barns are dimensioned according to the heat-moisture balance, the relative humidity, temperature and harmful gases will not be a problem with regard to animal welfare.

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