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Estimation of Minimum Ventilation Requirement of Dairy Cattle Barns for Different Outdoor Temperature and its Affects on Indoor Temperature: Bursa Case

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Abstract: In the study, 10 different dairy cattle barns with natural ventilation system were investigated in terms of structural aspects. VENTGRAPH software package was used to estimate minimum ventilation requirements for three different outdoor design temperatures (-3, 0 and 1.7°C). Variation in indoor temperatures was also determined according to the above-mentioned conditions. In the investigated dairy cattle barns, on condition that minimum ventilation requirement to be achieved for -3, 0 and 1.7°C outdoor design temperature and 70, 80% Indoor Relative Humidity (IRH), estimated indoor temperature were ranged from 2.2 to 12.2°C for 70% IRH, 4.3 to 15.0°C for 80% IRH. Barn type, outdoor design temperature and indoor relative humidity significantly ($p<0.01$) affect the indoor temperature. The highest ventilation requirement was calculated for straw yard (13879 m^3 h^{-1}) while the lowest was estimated for tie-stall (6169.20 m^3 h^{-1}). Estimated minimum ventilation requirements per animal were significantly ($p<0.01$) different according to the barn types. Effect of outdoor design temperatures on minimum ventilation requirements and minimum ventilation requirements per animal was found to be significant ($p<0.05$, $p<0.01$). Estimated indoor temperatures were in thermoneutral zone (-2 to 20°C). Therefore, one can be said that use of naturally ventilated cold dairy barns in the region will not lead to problems associated with animal comfort in winter.

Key words: Cattle, barn, minimum ventilation, Indoor temperature

INTRODUCTION

Proper ventilation in needed to provide a healthy and productive environment for livestock and farm workers. A well-designed ventilation system provides an adequate amount of fresh air to supply oxygen, remove excess moisture and control temperature (Chastain, 2000).

Without adequate fresh air supply within a livestock enclosure, animal comfort and welfare are drastically reduced, especially during high-density occupation by poultry, pigs or cattle, where high levels of moisture, heat and internal gases are generated. The lack of effective ventilation rate control is a major cause of production losses and health problems in modern livestock buildings (Stables and Taylor, 2006).

The outdoor design temperature should be selected for the particular area where the animal shelter will be located. The cold weather temperature is normally used for determining heat loss from a building, insulation requirements and minimum continuous air exchange rate. The summer design temperature is used to determine the maximum required ventilation capacity (ASAE, 2001). Aim of winter ventilation is to remove excess moisture and consequently keeps indoor relative humidity in desired level (Olgun, 1991). Therefore, winter ventilation capacity is adjusted to run minimum level.

Expected function of a ventilation system in winter months is to create desired indoor temperature as well as removing excess moisture. Therefore, minimum ventilation requirement must be determined and considered to design ventilation system components.

There are several model-aided approaches to determine the minimum ventilation requirement (Albright, 1990; CIGR, 1984, 1992; Pedersen *et al*., 1998; ASAE, 2001). Ventilation Graph (VENTGRAPH) describes the required ventilation rate as a function of outdoor temperature according to several criteria such as temperature control, humidity control and carbon dioxide control (Albright, 1990).

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The objectives of the study were to estimate the minimum ventilation requirement based on three different outdoor design temperatures (-3, 0 and 1.7°C) for Bursa region (Turkiye); to determine the effects of different outdoor design temperatures and indoor relative humidity values on indoor temperature and minimum ventilation requirements variations; to find out the effects of barntype on minimum ventilation requirements, minimum ventilation requirements per animal and indoor temperature and to determine the relationship between minimum ventilation requirements, indoor temperature and barn structural characteristics and effects of these characteristics on minimum ventilation requirements and indoor temperature.

MATERIALS AND METHODS

The study was carried out during 2001 and 2002, in Bursa, located on 40°15′29″ N and 28°53′39″ E and about 100 m above sea level, Turkiye. In the study, 10 different dairy cattle barns were investigated. The barns were selected according to the barn type, herd size and barn structural components' characteristics. Some characteristics of the examined barns were presented in Table 1.

In the selection process, it is considered that each barn type and capacity (small, medium and large) to be represented. Whole barns in selected enterprises are closed type and have skeletal construction.

Types of structural materials used in the barns were given in Table 2. Whole barns have concrete floors. In the enterprises, that roof materials are asbestos cement sheet and tile, covering materials are installed on veneering.

Minimum ventilation rates for different Outdoor Design Temperatures (ODT) were estimated using VENTGRAPH (Albright, 1990) software package, which allows carbon dioxide, moisture and temperature control.

For the ODT, -3 and 0°C, which are possibly occurred in 99 and 95% of the whole winter period in Bursa, respectively (Olgun, 1997) and 1.7°C, which is long-term average minimum temperature (Anonymous, 2000) were used.

For the Outdoor Relative Humidity (ORH), the coldest month's average relative humidity value (Olgun *et al*., 1988) was considered. Therefore, ORH value was determined as 74% (Anonymous, 2000) from the long-term meteorological data. Indoor Relative Humidity (IRH) values were assumed to be 70% (Anonymous, 2001) and 80% for the analysis to effects of different relative humidity values on ventilation requirement and indoor temperatures. For the outdoor and indoor CO_2 concentration, respectively 345 and 5000 mg kg^{-1} (upper critical limit) values were considered (Albright, 1990).

Analysis of 9 variance was carried out on all the examined parameters using General Linear Models (GLM) procedure of MINITAB 14 (2003) and multiple regression analysis between minimum ventilation requirement, indoor temperature and heard size, barn width, barn length, sidewall height ridge height were conducted using and Regression procedure of MINITAB 14. Differences

Table 1: Some characteristics of examined dairy cattle barns

Enterprise No.	Herd size (head)	Barn type	Row No.	Barn width (m)	Barn length (m)	Sidewall height (m)	Ridge height (m)
1	20	Tie-stall	2	8.20	14.00	3.00	5.00
2	48	Tie-stall	2	10.10	32.05	3.50	5.00
3	70	Tie-stall	2	9.00	40.00	2.70	-
4	20	Tie-stall	2	6.70	14.60	2.10	2.50
5	40	Tie-stall	2	9.60	21.70	2.90	5.00
6	46	Straw yard	-	8.90	24.80	3.00	4.50
7	80	Straw yard	-	14.10	64.70	3.00	5.00
8	20	Free-stall	2	7.75	15.40	3.50	6.00
9	46	Free-stall	2	13.00	50.00	3.50	5.00
10	78	Free-stall	2	15.80	50.00	5.00	7.00

Table 2: Type of structural materials

Enterprise No.	Wall	Roof	Windows	Doors
1	Perforated brick, without plaster and render	Tile	Glass	Wooden
2	Perforated brick, with plaster	Asbestos cement sheet	Glass	Steel
3	Solid brick, with plaster	Concrete	Glass	Steel
4	Perforated brick, with plaster	Asbestos cement sheet	Glass	Steel
5	Perforated brick, with plaster and render	Tile	Glass	Steel
6	Perforated brick, with plaster and render	Asbestos cement sheet	Glass	Steel
7	Perforated brick, with plaster and render	Asbestos cement sheet	Glass	Steel
8	Solid brick, with plaster	Tile	Glass	Steel
9	Perforated brick, with plaster and render	Asbestos cement sheet	Glass	Steel
10	Solid brick, with plaster and render	Asbestos cement sheet	Curtain	Steel

between variances were analyzed along with Duncan's multiple range test of MSTAT, C. Results were expressed as means with their standard errors. All statements of significance are based on a probability level of 0.05.

RESULTS AND DISCUSSION

Indoor temperatures versus estimated minimum ventilation requirement for the different ODT were presented in Fig. 1. It was determined that indoor temperatures were ranged from 2.2 to 8.6°C for -3°C, 4.7 to 10.8°C for 0° and 6.40 to 12.20°C for 1.7°C ODT. The ideal temperature for a dairy cow is between 5 to 25°C (Jones and Stallings, 1999). Estimated indoor temperatures for -3°C ODT were higher than 5°C in 60% of the investigated enterprise. Estimated indoor temperatures for 0°C were lower (4.7°C) than 5°C in only 10% of the enterprises. For the 1.7°C ODT, indoor temperatures in all enterprises were in the range of 5 to 25°C ideal ambient temperatures.

In all enterprises, estimated indoor temperature values were ranged within thermo-neutral zone (-2 to 20°C) suggested by Armstrong and Hillman (1999).

As can be seen from Table 3, minimum ventilation requirements in all enterprises were the highest for 0°C and the lowest for -3°C ODT. Estimated minimum ventilation requirements for 1.7°C ODT took the values

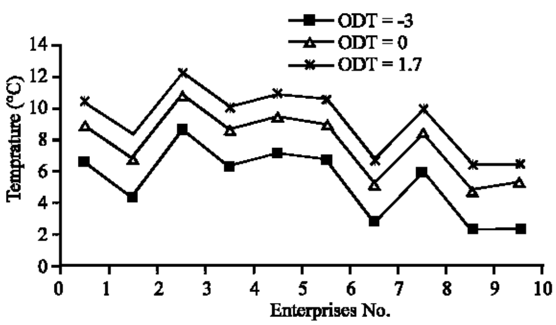

Fig. 1: Variation in indoor temperature based on selected ODT for 70% IRH

Table 3: Variation in minimum ventilation requirement based on selected ODT for % 70 IRH

	Minimum ventilation requirements (m^3 h^{-1})		
Enterprise No.	ODT = -3°C	ODT = 0°C	ODT = 1.7°C
1	3816	3924	3888
2	12240	12924	12564
3	10980	11196	11160
4	3960	4068	3996
5	7164	7380	7272
6	8712	8964	8820
7	26946	29772	28440
8	4068	4212	4140
9	15912	17280	16668
10	27864	31644	30276

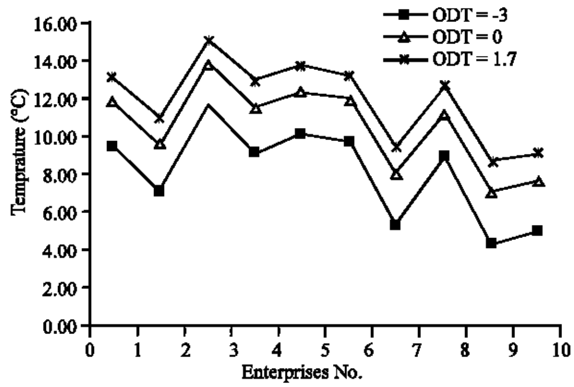

Fig. 2: Variation in indoor temperature based on selected ODT for 80% IRH

between that estimated for-3°C and 0°C. This may be resulted from increase in indoor temperature proportionally to rise in outdoor temperature and consequently decrease in sensible heat produced by dairy cows. Additionally, when indoor temperature is increase, amount of moisture given to environment is also increase. The largest differences among estimated minimum ventilation requirements for the selected three outdoor design temperatures were observed in enterprise 10, followed by enterprise 7 and 9 (Table 3). Ventilation requirements differences were maximum between -3 and 0°C and minimum between 0 and 1.7°C.

Variation in ODT did not significantly effect the ventilation rate, as can be seen from the Table 3. To determine the effects of relative humidity on ventilation rate, assuming indoor relative humidity was 80%, indoor temperatures and minimum ventilation requirements for the same ODT were estimated and presented in Fig. 2 and Table 4.

Estimated indoor temperatures were ranged from 4.3 to 11.6°C for -3°C ODT, from 7.0 to 13.8°C for 0°C ODT and from 8.6 to 15.0°C for 1.7°C ODT (Fig. 2). In all enterprises except enterprise 9, where indoor temperature was estimated as 4.3°C for-3°C ODT, estimated indoor temperatures for each three ODT were in the range of 5 to 25°C, which is suggested as ideal ambient temperature range by Jones and Stallings (1999).

For the 80% IRH, minimum ventilation requirements was decreased when ODT was increased. Similarly, temperature differences between indoor and outdoor were decreased when ODT was increased. The reasons for decrease in ventilation requirement with the decrease in temperature differences is indoor temperature rise consistent with the increase in outdoor temperature.

No significant difference among minimum ventilation requirements, estimated for 80% IRH, was observed (Table 4). For the each three ODT, the highest ventilation requirement was estimated for enterprise 10, following

Table 4: Variation in minimum ventilation requirement based on selected ODT for 80% IRH

	Minimum ventilation requirements ($m^3 h^{-1}$)		
Enterprise No.	ODT = -3°C	ODT = 0°C	ODT = 1.7°C
1	2340	2304	2268
2	6804	6696	6552
3	7092	7092	7020
4	2376	2376	2340
5	4464	4428	4392
6	5328	5292	5220
7	13320	13032	12708
8	2448	2412	2376
9	8568	8352	8136
10	13500	13212	12888

Table 5: Variation in minimum ventilation requirement per animal based on selected ODT for 70% IRH

	Minimum ventilation requirements ($m^3 h^{-1}$ head)		
Enterprise No.	ODT = -3°C	ODT = 0°C	ODT = 1.7°C
1	191	196	194
2	255	269	262
3	157	160	159
4	198	203	200
5	179	185	182
6	189	195	192
7	337	372	356
8	203	211	207
9	346	376	362
10	355	406	388

Table 6: Variation in minimum ventilation requirement per animal based on selected ODT for 80% IRH

	Minimum ventilation requirements ($m^3 h^{-1}$ head)		
Enterprise No.	ODT = -3°C	ODT = 0°C	ODT = 1.7°C
1	117	115	113
2	142	140	137
3	101	101	100
4	119	119	117
5	112	111	110
6	116	115	113
7	167	163	159
8	122	121	119
9	186	182	177
10	173	169	165

enterprise 7 and 9. The reason for ventilation requirements of these three enterprises was higher than the others is having relatively low indoor temperatures as well as large herd sizes. Because, the more decrease in indoor temperatures the less heat produce by animals.

Minimum ventilation requirements per animal (500 kg live-weight) were also estimated in the investigated enterprises (Table 5 and 6). Estimated minimum ventilation requirements for 80% IRH were quite lower than those for 70% IRH. Indoor temperatures, estimated for three ODT and 80% IRH, were 2.10 to 3.00°C higher than those for 70% IRH in all enterprises.

No significant differences observed among minimum ventilation requirements of enterprises, which have same herd size. Ventilation requirement difference between only enterprise 2 and 6, which have almost same herd size, was high. Because all other conditions were same, differences in barn sizes, overall heat transfer coefficient and consequently overall heat loss led to high ventilation requirement difference. High heat transfer leads to decrease in indoor temperatures and low indoor temperatures leads to increase in sensible heat produced by animals. Therefore, ventilation requirement of enterprise 2, in which overall heat transfer is high (1685.6 WK^{-1}), was higher than the enterprise 6 (1053.0 WK^{-1}).

Table 7: Effect of barn type, ODT and IRH on minimum ventilation rate, minimum ventilation rate per animal and indoor temperature

Parameters	Q ($m^3 h^{-1}$)±SE	Q ($m^3 h^{-1}$ head)±SE	t (°C) ±SE
Barn type	**	**	**
Tie-stall	6169.20±211.09^c	158.13± 2.67^c	10.04±0.04^a
Straw yard	13879.50±211.09^a	206.17± 2.67^b	8.18±0.04^b
Free-stall	12442.00±211.09^b	237.11± 2.67^a	6.99±0.04^c
ODT (°0C)	*	**	**
-3	9395.10±115.62^c	188.25± 1.46^b	6.65± 0.02^c
0	9828.00±115.62^a	195.45± 1.46^a	9.08±0.02^b
1.7	9556.20±115.62^b	190.60± 1.46^b	10.53±0.02^a
IRH (%)	**	**	**
70	12675.00±94.40^a	249.50± 1.19^a	7.38±0.02^b
80	6511.20±94.40^b	133.37± 1.19^b	10.13±0.02^a
BT x ODT	NS	NS	**
Bt x IRH	**	**	**
ODT x IRH	**	**	NS

a, b, c; Means in a column with different superscripts significantly differ *$p<0.05$, **$p<0.01$

In the study, as well as ODT and IRH, effect of different barn types on minimum ventilation requirements, minimum ventilation requirements per animal and indoor temperatures was also investigated with factorial analysis. Obtained results from analysis of variance were presented in Table 7.

Ventilation requirement and indoor temperature values for different barn types, ODT and IRH were calculated and given in Table 7. Barn type significantly affected ($p<0.01$) the minimum ventilation requirements and indoor temperatures. While the highest ventilation requirements were estimated for straw yard (13879.50 $m^3 h^{-1}$), the lowest ventilation requirements were calculated for tie-stall (6169.20 $m^3 h^{-1}$). This may be resulted from better insulation capacity of litter materials used in the barns, consequently lower heat loss and average capacities of selected straw yard barns were relatively higher than the others. Minimum ventilation requirements per animal were significantly different for each barn type ($p<0.01$). Due to average capacity of selected free-stall barn were lower, higher ventilation requirements per animal were estimated for this barn type (237.11 $m^3 h^{-1}$ head). ODT significantly effected the minimum ventilation requirements and ventilation requirements per animal ($p<0.05$, $p<0.01$). Higher values for both variables were obtained in 0°C ODT (9828 $m^3 h^{-1}$, 195.45 $m^3 h^{-1}$ head). Effecting ODT to indoor temperature and leading different indoor temperature to occur different IRH all led to significant differences among minimum ventilation requirements. According to the results, for the different IRH minimum ventilation requirements and minimum ventilation requirements per animal were significantly different ($p<0.01$). Minimum ventilation requirements and minimum ventilation requirements per animal were estimated as higher for 80% IRH than those 70% IRH (12675 $m^3 h^{-1}$, 249.5 $m^3 h^{-1}$ head). Because, software used in the study (VENTGRAPH) is run based on the CO_2, temperature and humidity balance. Therefore, indoor temperatures estimated for ventilation requirements for two-selected relative humidity were greatly differing in the same ODT. Additionally, sensible heat production was estimated as higher for 70% IRH than those 80% IRH and latent heat production was lower.

Effects of investigated each three parameters in the study on indoor temperature were significant ($p<0.01$). Highest values for barn type, ODT and IRH were obtained for tie-stall barns (10.04°C), 1.7°C ODT (10.53°C) and 80% IRH (10.13°C), respectively. Higher indoor temperatures in tie-stall barns may be attributed to continuous handling of cattle in the barn in whole growing period and thus all metabolic activities to be realized in the barn. Due to higher indoor temperature is expected case based on the rise in outdoor temperature, the highest indoor temperature was observed for 1.7°C ODT.

According to the variance of analysis' results, interactions among parameters were found to be significant for some variables, while others were not significant. Accordingly, it was determined that barn type x ODT interaction has significant effect on only indoor temperature, barn type x IRH interaction significantly effected the whole variables and ODT x IRH interaction has significant effect on whole variables except indoor temperature.

In the study, regression analysis was also employed to determine whether there was a relationship between minimum ventilation requirement (MV) (dependent variable, Y) and Indoor Temperature (IT), Herd Size (HS), Barn Width (BW), Barn Length (BL), Sidewall Height (SH) and Ridge Height (RH) (independent variables, X). To determine whether there was a relationship between indoor temperature (dependent variable, Y) and minimum ventilation requirement, herd size, barn width, barn length, sidewall height and ridge height (independent variables, X) another regression analysis was also applied.

Regression equation in the case of minimum ventilation requirement is dependent variable (Y);

$$MV = 11167-2038\,IT + 313\,HS+1107\,BW-177\,BL-1333\,SH +120\,RH$$

According to the variance of analysis for regression equation, minimum ventilation requirement was found to be dependent to all independent variables included in the test ($p<0.01$). The value of R^2 for this regression was determined as 98.3%. Therefore, collective effects of independent variables on minimum ventilation requirement and value of these relationships for predictive purposes were relatively high. This regression equation can be used to estimate minimum ventilation requirement in Bursa for different values of variables included in the equation, as depicted by an R^2 value of 98.3% and statistically significant of regression equation ($p<0.01$).

Regression equation in the case of minimum ventilation requirement is dependent variable (Y);

$$IT = 9.05+0.155\,BW-0.110\,BL-0.502\,SH-0.100\,RH+0.119\,HS-0.000250\,MV$$

According to the results of regression analysis, indoor temperature (Y) was significantly varied depending on the independent variables ($p<0.05$). Estimated an R^2 value of 95.7% verified the high collective effects of herd size, barn width, barn length, sidewall height and ridge height on indoor temperature variation and value of these relationships for predictive purposes. Consequently obtained regression equation can be used statistically to estimate indoor temperature in Bursa for different values of variables included in the equation ($p<0.05$).

CONCLUSIONS

Effects of outdoor temperature variations on minimum ventilation requirements were relatively lower than the relative humidity variations. Estimated ventilation requirements for 80% IRH were about one-half of estimated ventilation requirements for 70% IRH. Additionally, estimated indoor temperatures for 80% IRH were also in the range of ideal ambient temperatures, 5 to 25°C (Jones and Stallings, 1999).

Overall heat transfer of a building has effect on required ventilation rate and indoor temperature. For the same outdoor temperature, the higher minimum ventilation requirement was estimated in enterprises, which have higher heat transfer capacity. Consequently, estimated indoor temperature was lower in these enterprises than the others. Therefore, these conditions should be considered in the selection of barn structural components and materials, which provide better insulation, must be chosen.

Due to estimated indoor temperatures were in the range of thermo-neutral zone (-2 to 20°C), use of naturally ventilated cold dairy barns in the region will not lead to any problem related to animal comfort in winter months.

In the study, applied analyses of variance and regression indicated that minimum ventilation requirement and indoor temperature were significantly affected by barn type, outdoor temperature and indoor relative humidity and were considerable depended herd size, barn width, barn length, sidewall height, ridge height and considering these independent variables in planning of cold dairy barns in Bursa will be useful. Additionally, obtained regression equations can be used to estimate minimum ventilation requirement and indoor temperature during a new enterprise planning for Bursa region in Turkiye.

To test the applicability of cold dairy barns in the region it will be useful that carrying out the future studies included direct measurements of environmental parameters such as temperature, relative humidity and air velocity in the existing cold barns.

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