Journal of Animal & Plant Sciences, 34(3): 2024, Page: 547-556
ISSN (print): 1018-7081; ISSN (online): 2309-8694
https://doi.org/10.36899/JAPS.2024.3.0741

EFFECTS OF NATURAL VENTILATION SYSTEM WITH UNDERGROUND PIPE ON CALF BARN CONDITIONS IN WINTER

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*This article is derived from Ph.D. Thesis

ABSTRACT

The aim of the present study was to investigate the effects of natural ventilation system with underground pipe which is an alternative ventilation system for temperature, relative humidity and air flow rate parameters in the calf stall indoor environment during the winter, when animals continuously stay in the barn. The temperature, relative humidity and air flow rate values of stall interior and outdoor air were continuously measured during the months of December, January, February, March by applying natural ventilation system with underground pipe and traditional ventilation system with windows in a 48 head calf barn with a floor area of 150 m^2. Measured parameters in both ventilation systems were statistically compared.In the wake of implementing; It has been observed that the natural ventilation system with underground pipe in the calf barn in frigid meteorological conditions has a statistically better good achieve on the temperature, relative moisture and air flow rate criteria inside the stall than the traditional ventilation system carried out with windows.In the natural ventilation system with underground pipe, the outside air is taken from the exterior surface of ones of the lengthy sides of the barn, passes under the barn floor transversely and enters the stall from inner surface of the other lengthy side of the barn. Thus, outside air coming in the stall through underground pipes becomes warmer than the outside air picked up into the barn by windows. In addition, since the air taken into the barn with the underground pipe ventilation system penetrates directly into the ground and comes out of the chimneys, it allows the air inside the barn to be cleaned faster than traditional ventilation systems.

Keywords: calf stable, natural ventilation, underground piped natural ventilation, temperature, relative humidity

Published first online March 22, 2024 Published final May 31, 2024

INTRODUCTION

It is likely with the creation of enough ventilation in animal shelters be kept the temperature, relative moisture and air flow rate at appropriate limits within shelter, evacuating polluted air out of the shelter, controlling the air inside the shelter (Yamak *et al*., 2016). Natural and mechanical ventilation is used in animal shelters. In taking the fresh outside air into the shelter; are utilized from the apertures planned under the eaves, designed on the roof ridge made on the side walls of the building, through gaps of window and door, through crevices and fissures in the structure, from ventilation flues (Mylostyvyi *et al*., 2020). However; air intake to structures can also be carried out by means of ventilation systems with an underground pipe whose mouth opens to outside air in structures such as cold storage depots, intensive care units of hospitals, underground transport stations, and housing (Liu *et al*., 2021; Bulakh and Merylova, 2020; Yu *et al*., 2021).

In this study; It has been explored the effectiveness of Natural Ventilation With Underground Pipe which is an alternative ventilation system for keeping within appropriate limits of temperature, relative moisture, and airflow rate in cold climate conditions in the winter season which animals stay in the shelter all the time.

MATERIALS AND METHODS

For this sake of; Natural Ventilation System with Underground Pipe has been applied during construction of 48 head calf barn with a floor area of 150 m^2 that constructed in the cattle business facility within the body ofAgriculture Business Directorate of Agricultural Faculty of Atatürk University. In the calf barn, one day the windows were closed, ventilation was carried out through the natural ventilation system with underground pipe and the next day natural ventilation system with underground pipe was closed, ventilation was carried out through the windows.The research was conducted in this way between December 01, 2014 - March 31, 2015.

Background and material of the study constitute: A calf barn with a capacity of 48 calves and a floor area of 150 m^2 built in Erzurum Atatürk University Faculty of Agriculture Research and Application Farm (Fig. 1), and a total of 48 calves including 24 Swiss brown breeds, 15 Holstein breeds, 4 crossbreeds and 5 local breeds, which hosted in this barn during the research.

In the research, the barn used Digital Humidity and Temperature meter that is capable of measuring temperature in the range of 0.0 ºC - +50.0 ºC and relative humidity within the 20.00% - 90.00% range also Anemometer/Psychrometer Data Logger that is able to measure temperature in the range of -20.00 ºC - +60.00 ºC and relative humidity within 0.00% - 100.00% range and air flow rate within 0.01 m/s – 25.00 m/s range.

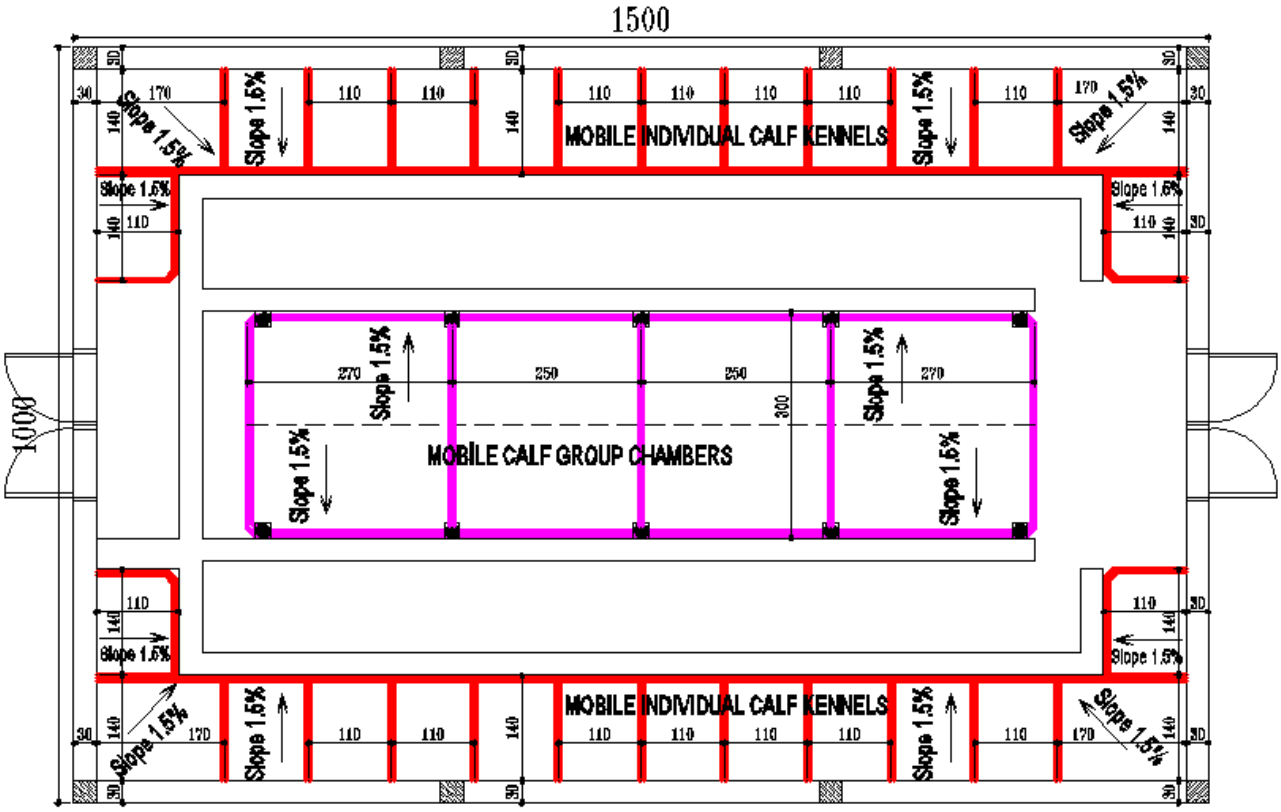


Fig 1. Design of calf chambers on the floor of calf barn with a capacity of 48 calves.

Plan and design of calf barn, selection and dimensioning of building elements was made according to the principles stated in Okuroğlu and Yağanoğlu (2015), Nordlund and Halbach (2019).

Calf barn foundation has been raised as the floor of its to be 70 cm higher than the ground. In foundation, a total of 12 underground ventilation pipes with each one 100 mm diameter have been settled transversely of barn from near the column bottoms (Fig. 2).

The height of the side wall is 3.5 m from the floor of the barn to the upper level of the beam. It is a 1.65 m ridge height of roof which has been made at 30% slope and in the form of a gable roof. 5 ventilation flues with the outlet port 50 cm above the ridge, 40x40 in size, placed staggered on the ridge were executed. The height difference between air outlet flues and the inlets of the underground ventilation pipes is 5.35 m, and 2.55 m with the Windows (Fig. 3).

It was abided by the formula $V = 110 \left[\frac{h(t_i - t_d)}{273 + t_d}\right]^{1/2}$ in air flow-rate calculations (Ekmekyapar, 1999; Okuroğlu and Yağanoğlu, 2015). The air flow-rate (77.98 m/min) that will occur when Natural Ventilation System with the Underground pipe is applied approximately is 1.5 times more than the air flow rate value (53.84 m/min) that will occur when a traditional ventilation system with Windows is carried out.12 windows with a total area of 6 m^2 were built on both long walls of the barn considering the principles set out (Ekmekyapar, 2001; Okuroglu and Yaganoglu, 2015; Olgun, 2016). The windows of 0.5 x 1.0 m are placed on each long wall of the barn, 3 of which are transom and 3 of which cannot be opened (fixed).

It was benefit from equations denoted in (Yaganoglu and Okuroglu, 1989; Kocaman *et al*., 2006; Rombach *et al*., 2019), for heat stability calculations, in

(Ekmekyapar, 1999; Marciniak, 2014) on moisture balance computations and in (Ekmekyapar, 1999; Okuroglu and Yaganoglu, 2015) to determining the air flow rate and the size of the ventilation apertures.

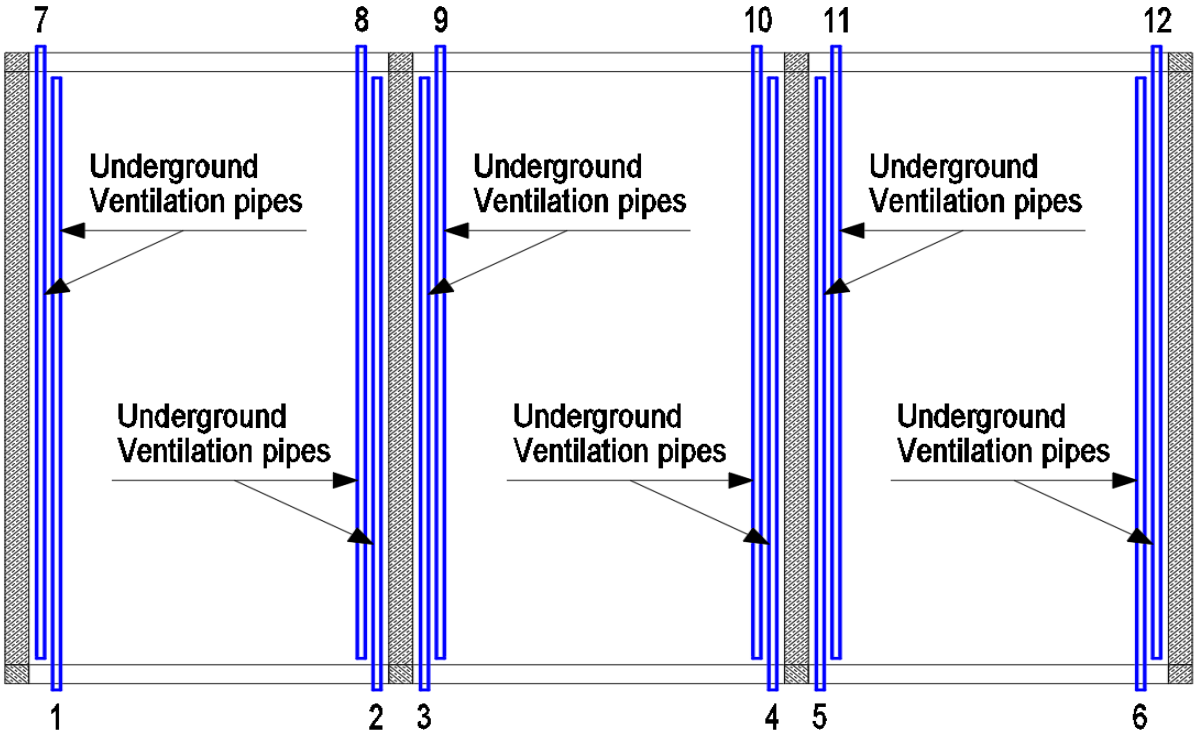


Fig 2. Laying plan of natural ventilation pipes with underground pipes.

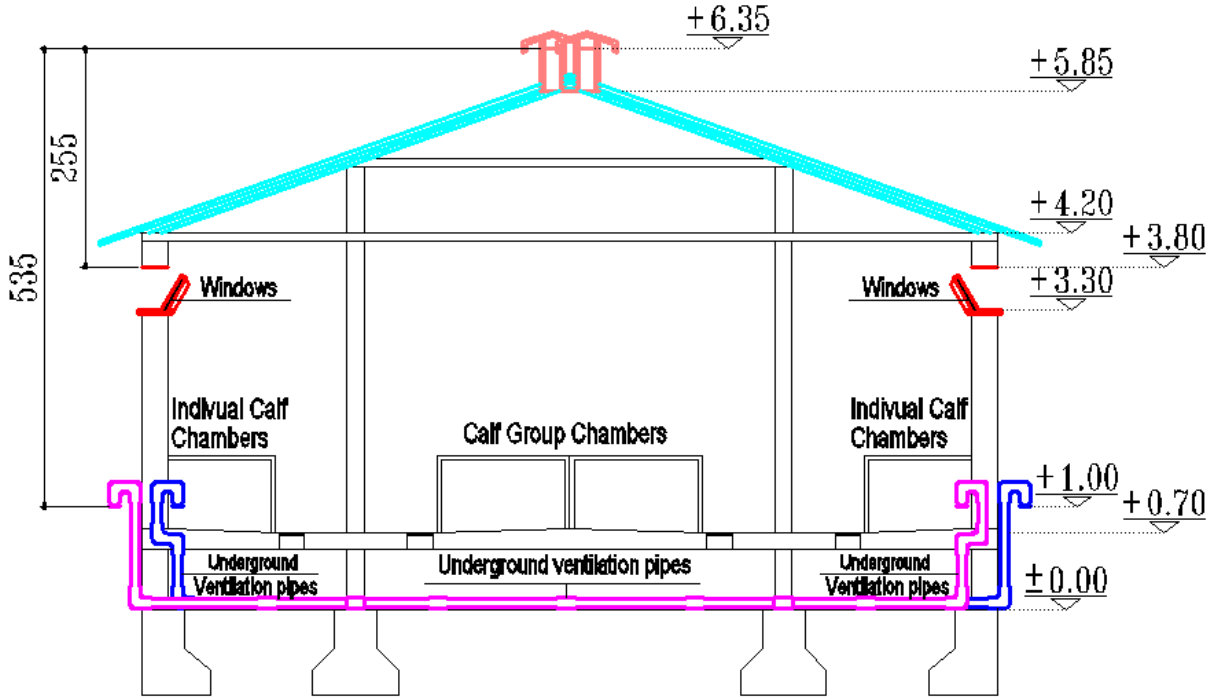


Fig 3. Cross section of calf barn.

Project internal temperature and indoor air relative moisture in the heat and moisture stability calculations in calf barn in the winter was taken as 10 ºC and 80%, respectively (Yaganoglu and Okuroglu, 1989; Ekmekyapar, 2001; Kocaman *et al*., 2006).It was accepted -14.3 ºC which is the coldest month average low temperature of the region as Project external temperature and value of 77% which is the average of the average

relative moisture values observed in December, January, February and March in Erzurum as relative moisture of outside air (Anonymous, 2022).It was acknowledged respectively as 15 ºC and %75 the temperature and relative humidity of indoor and respectively as 8 ºC and 63% the temperature and relative humidity of outside in mid season ventilation calculations (Okuroglu, 1988; Ekmekyapar, 1999; Marciniak, 2014).

The study has been performed from 01 December 2014 to 31 March 2015 for 4 months. During the time specified one day calf barn has been naturally ventilated with the underground pipe ventilation system by closing all the whole windows and the next day it has been naturally ventilated by way of the windows by totally closing the underground pipes.Ventilation system alterations in the barn have been implemented at 20:00 o'clock everyday (Okuroglu and Yaganoglu, 2015; Olgun, 2016). According to the studies on ventilation systems that is supported by the such rigorous research, once temperature and relative humidity of barn in are respectively 10 ºC and 80%, amount of ventilation per calf become 17 m^3/h in calf barns (Ekmekyapar, 2001). Amount of total ventilation in research barn is 816 m^3/h (48*17) and total volume of the barn is 648.75 m^3 [(10*15*3.5) + (10*15*1.65/2)]. All of the barn air is completely replaced every 0.80 hours (648.75/816).In the barn, approximately 0.80 hours after the air intake system is changed, the effect of the previous ventilation system completely disappears and ventilation is provided with the effect of the altered ventilation system. The measurements were taken 12 hours after the active ventilation system was turned off and the other ventilation system was started. Put it differently, measurements started to be taken after the air inside the barn changed approximately 15 times (12/0.80). It means that entirely stands for the properties of ventilation system that measurements are taken.

During the term of the study, measurements of temperature, relative humidity and air flow rate were carried out inside and outside the barn. All measurements were taken three times everyday between 08-10, 13-15, and 18-20 hours (Yaganoglu *et al*., 1994). Values of temperature, relative humidity and air flow rate were recorded at 77 points in total were at underground pipes' air lead in, window and eaves levels that have 24 measuring points at every level inside the barn and at the lead out of 5 air flue (Fig. 4).Measurements were made every day both manually and with automated recording devices.

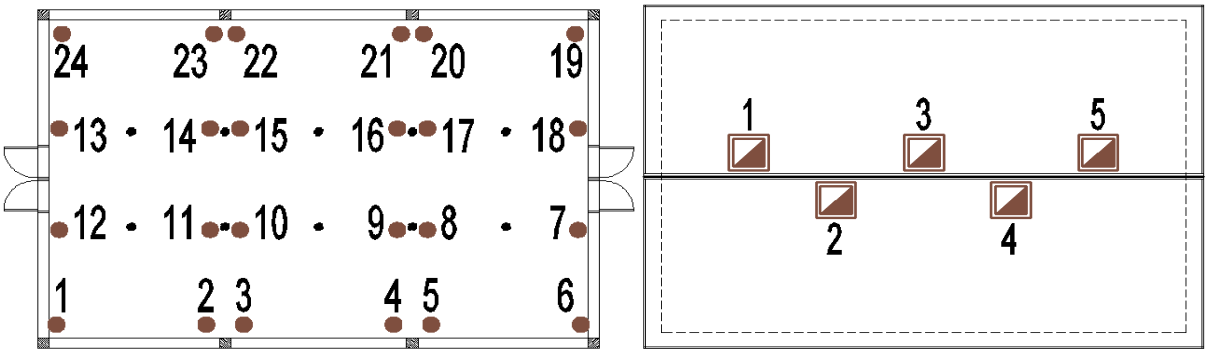


Fig 4. Measurement points of parameters inside the barn and on the ridge.

Data Analysis: In the duration of 121 days when the measurements were taken in the barn were implemented the natural ventilation system with underground pipe on the first, third, fifth, seventh, etc. days (odd-numbered days) and traditional ventilation system with windows on the second, fourth, sixth, eighth, etc. days (even-numbered days) from the first day of the study.The first and second days were handled as the first period, the third and fourth days as the second period and fifth and sixth days as the third period etc. in the evaluation process.

Maximum average, minimum average, mean of averages and standard deviation values were inspected by graphing seasonal distributions of daily averages of values of temperature, relative humidity and air flow rate measured in the barn.The values acquired once the calf barn was ventilated with underground pipe natural ventilation system were compared with the values attained when it was naturally ventilated with windows.

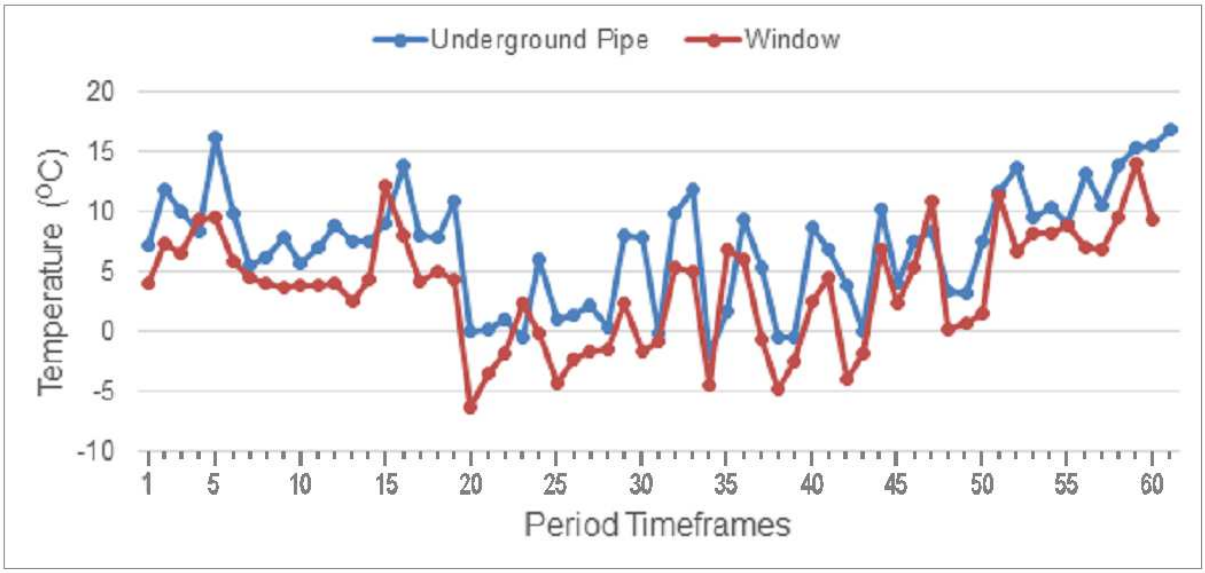
In the evaluation of the data statistical methods given in Kocaman *et al*. (2006) were used. Variance and Independent Sample T-Test were performed according to the criteria specified in Tan (2015) and Standard Deviation values were evaluated according to the principles specified in Lovarelli *et al.* (2020).

RESULTS AND DISCUSSION

Outdoor weather conditions: The difference between the temperature, relative humidity and air flow rate conditions of the outside air every other day (in two-day periods) was found to be negligible in the results of Variance and Independent Sample T-Test Analysis ($P > 0.05$).

Temperature: According to outcomes of Independent Sample T-test and Variance Analysis that were realized to the barn interior temperatures that were measured in natural ventilation that was actualized with underground pipes and windows, P values were respectively ascertained 0.901>0.05 and 0.000<0.05. Therefore, It is fixed that the relationship between the barn interior temperatures that were measured in natural ventilation that was actualized with underground pipes and windows was markedly different for Independent Sample T-test ends.

In natural ventilation systems that made by underground pipes and windows, The graph of the changes in the average values of the temperatures measured in the barn during the course of the research for each period is conferred in the (Fig. 5).



Period Timeframes: Days when the calf barn is operated with a natural ventilation system with underground pipes and natural ventilation system with windows

Fig 5. The changes of the average temperatures inside the barn.

Minimum average temperatures in both ventilation systems and mean average temperatures in natural ventilation performed with windows were achieved at a level where calves could maintain their body temperature. It is accentuated that calves can take care of their body temperature between -8°C and 27°C (Ekmekyapar, 1999; Ozcan and Gurçay, 2000; Altıncekic and Koyuncu, 2010). The mean average temperature in the underground pipe natural ventilation system is between 7°C and 20°C which are appropriate temperatures (Yaganoglu and Okuroglu, 1989; Ekmekyapar, 2001). It is stated that is between 10°C and 15°C for the optimum temperature which is called the comfort zone for calves (Ekmekyapar, 1999; Kutlu and Serbester, 2014; Fig. 6). The standard deviation values were respectively calculated as 4.77 and 4.71 in natural ventilation systems with underground pipe and windows. It has been observed that the deviation risk from the mean of the temperatures in the natural ventilation system made with windows is 1% less than in the underground pipe natural ventilation system.

As a result of the Analysis of the Independent Sample T-test and Variance implemented to the relative humidity measured in both ventilation systems in the barn, P values were 0.143>0.05 and 0.000<0.05, respectively. Accordingly, it is meaningful the difference between the relative humidity quantities in both ventilation systems for analysis of variance.

Relative humidity: In Fig. 7, the graph of the alterations in the daily averages of the relative humidities measured in the barn during the course of the research in natural ventilation systems that are actualized with underground pipes and windows is in sight to each period. In both ventilation systems, the minimum average relative humidity values remained below the appropriate relative humidity values. Thus this situation may give rise to respiratory tract infections of calves and employees by increasing the dust and particles in the environment (Webster 1984; Okuroglu 1987).The mean average relative humidity values in both ventilation systems and the maximum average in the ventilation system that is made with windows are among the acceptable relative humidities. So and so, it is stated that between 50% and 75% of coherent relative humidity values for calf barns (Yaganoglu and Okuroglu, 1989; Ekmekyapar, 2001). The maximum average relative humidity has exceeded 80% in the underground pipe natural ventilation system. The circumstance may create dew and condensation inner

surface of building elements in the barns where the isolation is suboptimal and they may cause the animals become ill by distilling on the body of them. It is offered that the relative humidity in calf barns should not exceed 80% (Yaganoglu and Okuroglu, 1989; Ostas and Avki, 2015; Fig. 8). Relative humidity standard deviation values were respectively calculated as 9.44 and 7.61 in natural ventilation systems with underground pipe and windows. It has been observed that the deviation risk from the average of the relative humidities in the natural ventilation system made with windows is 19% less than in the underground pipe natural ventilation system.

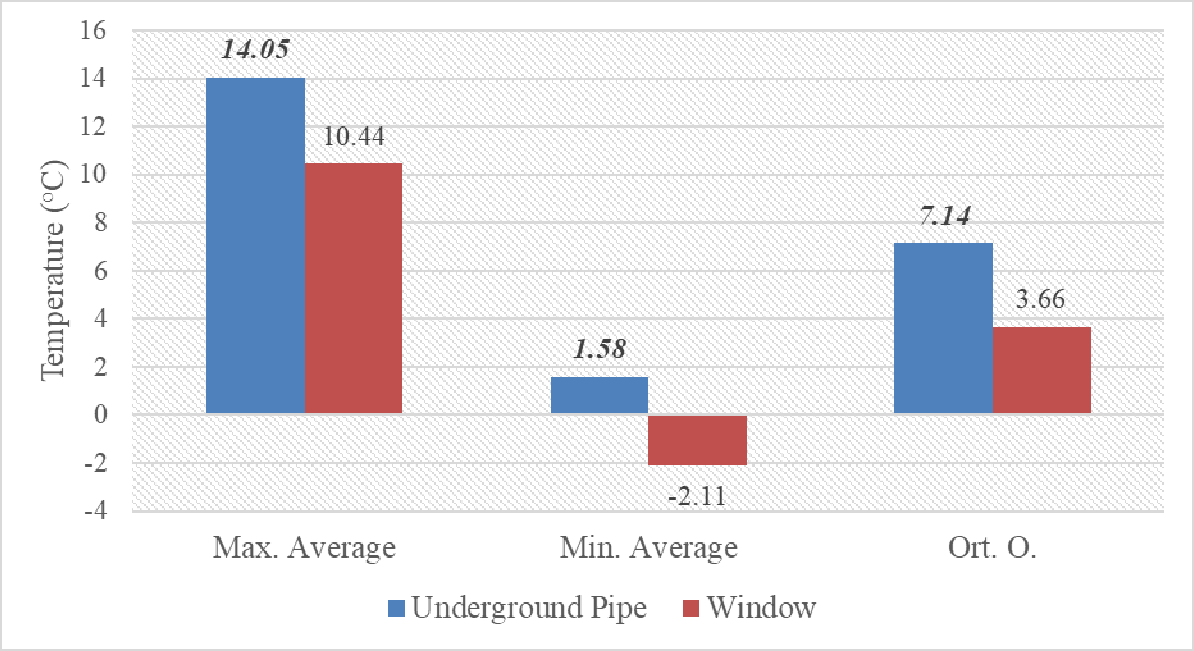
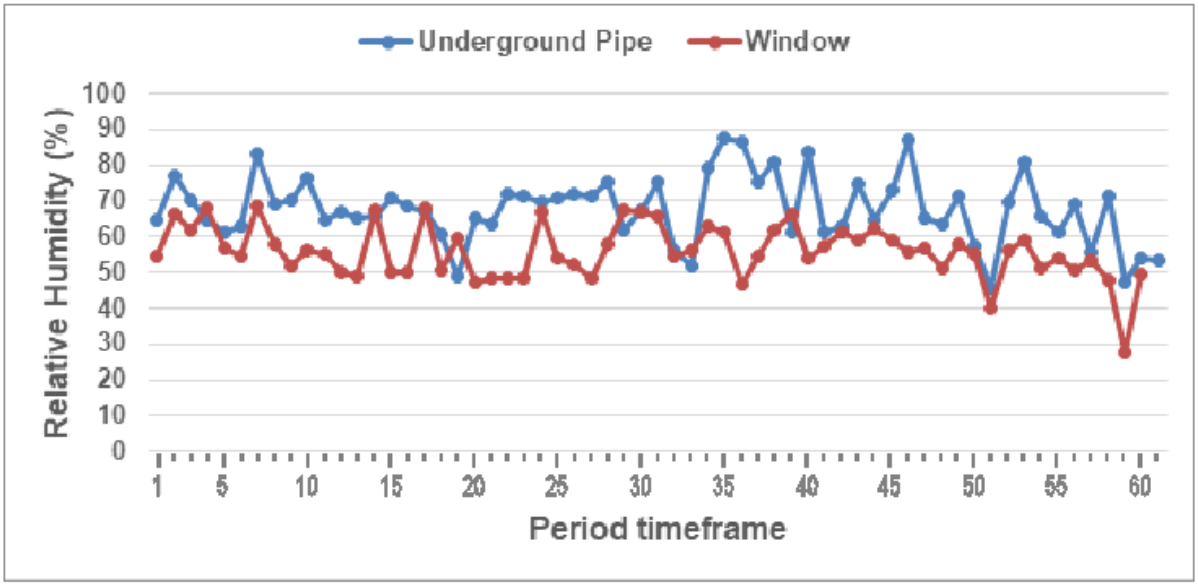


Fig 6. Maximum, minimum, and mean average temperatures values.



Period Timeframes: Days when the calf barn is operated with a natural ventilation system with underground pipes and natural ventilation system with windows

Fig 7. The changes of the average relative humidity values inside the barn.

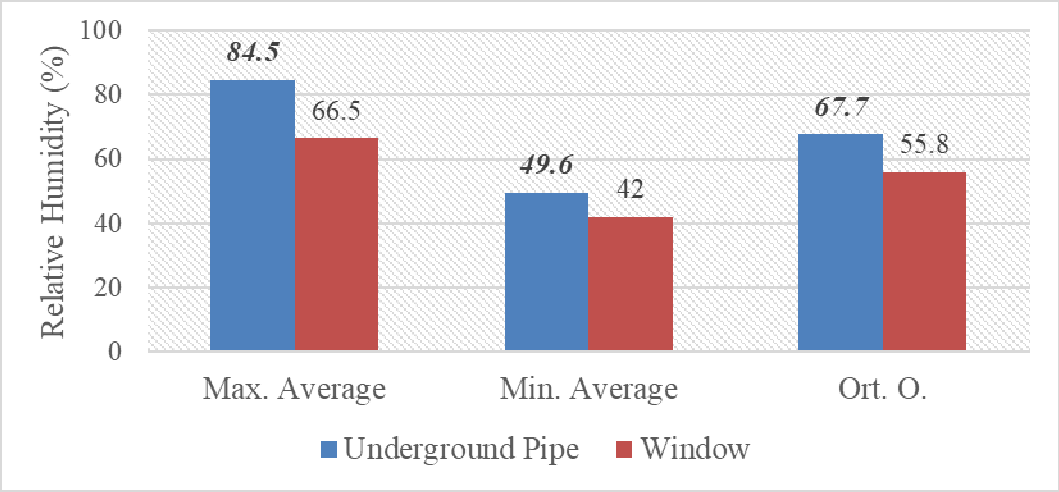
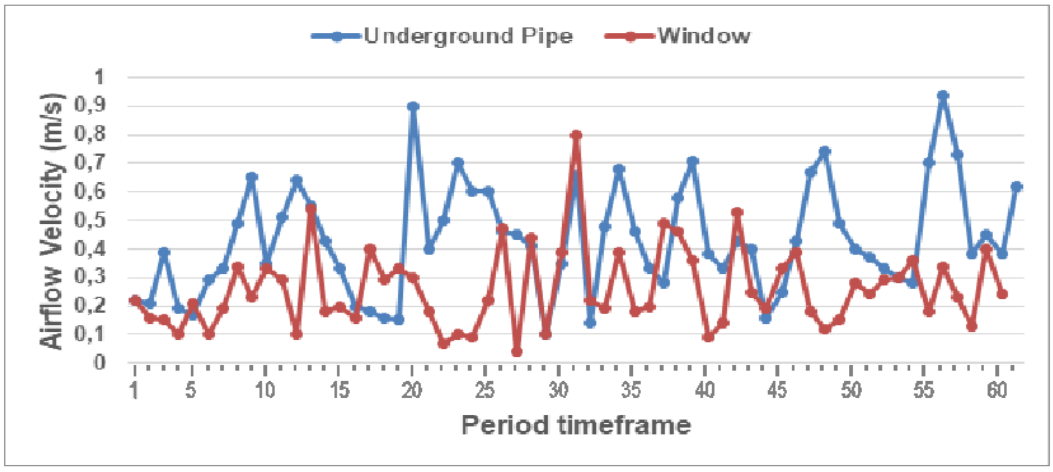


Fig 8. Maximum, minimum, and mean average relative humidity values.

Airflow velocity: P values of Independent Sample T-test and Variance Analysis of air flow rate that tracked in natural ventilation systems with the both underground pipe and windows are respectively 0.233>0.05 and 0.000<0.05. They are inform significant variation between the in both ventilation systems for air flow rate from the point of analysis of variance.

Graph about air flow rate interchanges in both ventilation systems in the barn has been given in Fig. 9. Since the maximum average air flow rate in the underground pipe natural ventilation system went over the limit the appropriate air flow rate values it may let current on animals and cause them to get sick (Matamala *et al*., 2022). In the underground pipe and window natural ventilation systems respectively the mean of averages and the maximum average air flow rates are among the conforming air flow rate values for calf barns. The appropriate air flow rate inside the barn in calf barns is between 0.3 m/s and 0.7 m/s (Wang *et al*., 2018; Matamala *et al*., 2022). The minimum average in both ventilation systems, the mean of the averages in ventilation system with window are less than 0.3 m/s. For this reason may emerge odour problem in the environment, respiratory tract infections in the animals and employees and may retard the growth of calves. As a matter of fact previous studies emphasized that lower threshold value of suitable air flow rates in calf barns in winter is 0.3 m/s (Okuroglu, 1987; Ekmekyapar, 1999; Olgun, 2016; Fig. 10). The standard deviation of airflow rate in the underground pipe natural ventilation system is 0.19 and It is 0.14 in the ventilation system with window. It has been determined that the deviation risk of the airflow rate values from the average in the ventilation system with window is 26% less than in the underground pipe natural ventilation system.



Period Timeframes: Days when the calf barn is operated with a natural ventilation system with underground pipes and natural ventilation system with windows

Fig 9. The changes of the average airflow velocity values inside the barn.

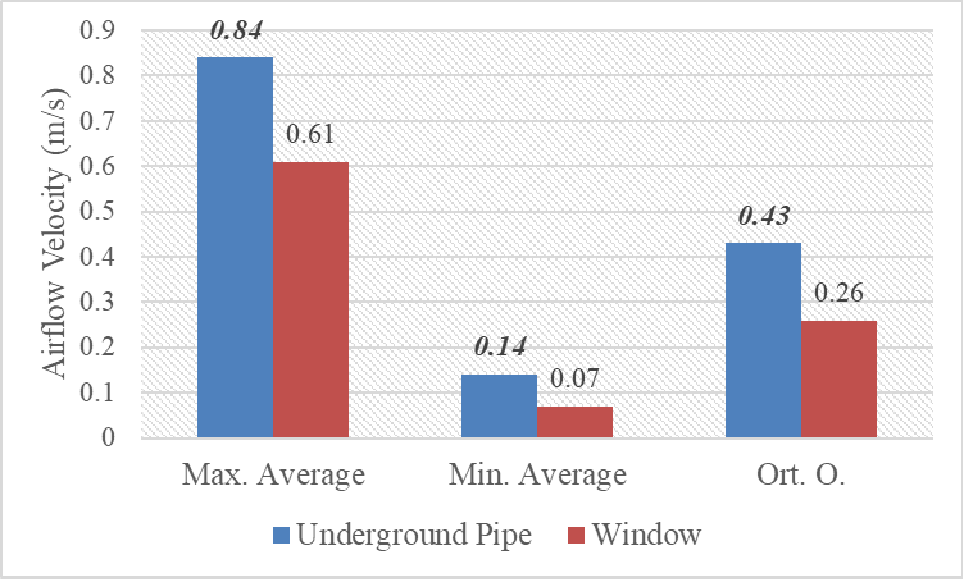


Fig 10. Maximum, minimum, and mean average airflow velocity values.

Comparison of temperature, relative humidity and air flow rate values measured inside and outside the barn in natural ventilation systems made with underground pipes and windows: The indoor air temperature was significantly affected by the outdoor air temperature in both ventilation systems and the effect was found more in the underground pipe natural ventilation system due to P1< P3 and P2=P4 in terms of ends of Analysis of Variance (Table 1).

Table 1. Analysis results for temperature values.

Underground Pipes		Windows	
Variance Analysis	**T-test Analysis**	**Variance Analysis**	**T-test Analysis**
Significance (Sig. 1) **P1**	Significance (Sig. 2) **P2**	Significance (Sig. 3) **P3**	Significance (Sig. 3) **P4**
0.002	**0.000**	**0.016**	**0.000**

The indoor air relative humidity was markedly affected by the outdoor air relative humidity in both ventilation systems and the effect was ascertained more in the underground pipe natural ventilation system by the reason of P1< P3 and P2=P4 as regards ends of Analysis of Variance (Table 2).

Table 2. Analysis results for relative humidity values.

Underground Pipes		Windows	
Variance Analysis	**T-test Analysis**	**Variance Analysis**	**T-test Analysis**
Significance (Sig. 1) **P1**	Significance (Sig. 2) **P2**	Significance (Sig. 3) **P3**	Significance (Sig. 3) **P4**
0.000	**0.000**	**0.007**	**0.000**

The indoor air flow velocity was seriously affected from the outdoor air flow velocity in both ventilation systems and it was not seen difference between the rates of exposure owing to P1= P3 and P2=P4 (Table 3).

Table 3. Analysis results for air flow velocity values.

Underground Pipes		Windows	
Variance Analysis	**T-test Analysis**	**Variance Analysis**	**T-test Analysis**
Significance (Sig. 1) **P1**	Significance (Sig. 2) **P2**	Significance (Sig. 3) **P3**	Significance (Sig. 3) **P4**
0.000	**0.000**	**0.000**	**0.000**

The temperature in the barn; on days when the underground piped natural ventilation system was applied was between 10°C and 15°C in 21% of the total time, between 7°C and 20°C in 60%, below 7°C in 40% and

below 0°C in 8%. It was detected that between 10°C and 15°C in 7% of the total time, between 7°C and 20°C in 23%, lower than 7°C in 77% and lower than 0°C in 26% in the days when the traditional ventilation system was implemented. Difference between measured temperatures in both ventilation systems is statistically substantial. Temperature in the barn in the underground piped natural ventilation system was positively influenced more than the traditional natural ventilation system with windows.

The relative humidity in the barn; it was determined between 50% and 75% in 75% of the total time, lower than 50% in 10%, upper than 75% in 15% and upper than 80% in 11% in the days when the underground piped natural ventilation system was carried out and on days when was practiced of natural ventilation system with windows as traditional was between 50% and 75% in 80% of the total time, lower than 50% in 20% and lower than 40% in 3%. Difference between measured relative humidity values in both ventilation systems is statistically considerable. In the underground piped natural ventilation system, relative humidity in the barn was affirmatively affected more than the traditional natural ventilation system with windows.

The air flow velocity in the barn; on days when the underground piped natural ventilation system was enforced is between 0.3 and 0.7 m/s in 67% of the total time, lower than 0.3 m/s in 25% and higher than 0.7 m/s in 8%. It was observed between between 0.3 and 0.7 m/s in 34% of the total time, lower than 0.3 m/s in 64% and higher than 0.7 m/s in 2% in the days when the traditional natural ventilation system was deployed.Difference between measured air flow velocity values in both ventilation systems is statistically significant. Air flow velocity in the barn in the underground piped natural ventilation system was favorable impressed more than the traditional natural ventilation system with windows.

Conclusion: The natural ventilation system with underground pipes is generally more suitable in terms of to accommodate calves raised in the barn in a suitable environment and to bring the temperature in the barn to the appropriate limits for the health of the caregivers, the creation of a calf barn with appropriate relative humidity in the barn that will positively affect the growth and development of calves, ensuring adequate ventilation for the health of calves and employees and can be developed and recommended as an alternative ventilation system in calf barns.

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