A Simple Procedure In Designing Dairy Barn Thermal Environment

Sefa Aksu[1], Unal Kizil[1], and Levent Genc[1]

***Abstract*—**Increasing enterprise expenses force the producers to use more efficient techniques for profitable operations in livestock production. Natural ventilation systems are sometimes the only choice for producers considering the energy fees. Applying natural ventilation systems in appropriate climate regions became essential. However, required ventilation rate calculations based on psychometrics can be a complicated process. Also variable ambient conditions are in need of continues monitoring, which is not possible for the producers. Dairy cows are more sensitive to higher temperatures than the lower temperatures. Nevertheless, both situations cause a decrease on milk productivity. THI (Temperature-Humidity Index) specify the animals' comfort level, which is inversely correlated to milk production. For this study, a simple procedure has created in MS Excel worksheet to determine the psychometrics, ventilation rate and THI from basic ambient data input.

***Keywords*—**dairy barn, natural ventilation, psychometrics, temperature-humidity index

I. Introduction

Animal production structures require ventilation to remove excess heat, water vapor, carbon dioxide, micro particles and provide fresh air [1]. Livestock must be housed under stress-free and healthy comfort conditions for a profitable production. Levels of indoor temperature and humidity significantly affect performance of lactating cattle. Higher or lower temperatures cause feeding disorder to maintain body temperature. Milk production decreases significantly [2].

Ventilation is provided mechanically or naturally in the livestock barns. Mechanical ventilation systems are necessary for warm-climate regions. However, energy requirements increase production costs. Natural ventilation is a system based on passive air movement and shows no need of energy consumption [3]. The use of natural ventilation system in suitable climatic zones is based on basis of providing environmental requirements of livestock constantly. Thus, system must be designed properly in the beginning [4]. Eaves are the inlet openings for fresh air and ridge is the discharge opening for heat, water vapor, carbon dioxide in design of natural ventilation system [1].

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Temperature-Humidity Index (THI) determines livestocks' stress against various ambient conditions [2].

A simple procedure, based on psychometric computations, was developed to determine required ventilation rate and THI stress category for dairy barns, which is located in mild-climate regions using MS Excel program.

II. Material and Methods

A. Psychometrics

Psychometrics, deals with the moist air thermodynamic properties for measured conditions to determine unmeasured conditions [3]. Altitude of the location (m), relative humidity (%) and temperature (^{o}C) values was used as input data. Psychometric properties calculated with the atmospheric pressure (Pa) which was achieved by correlative values from the properties of the standard atmosphere at various elevations. The psychometrics procedures are adapted from Albright [3] and wet-bulb equation adapted from Stull [5], (1).

Wet-bulb temperature from relative humidity and air temperature;

$$t_w = t\,atan[0.151977(\phi+8.313659)^{1/2}]+atan(t+\phi)-atan(\phi-1.676331)+0.00391838\,\phi^{3/2}\,atan(0.023101\phi)-4.686035 \quad (1)$$

where:

t= dry-bulb temperature (^{o}C)

ϕ= relative humidity (%)

B. Steady-state thermal analysis

Calculations start with the structural data input such as window, wall, door, roof and roof truss dimensions.

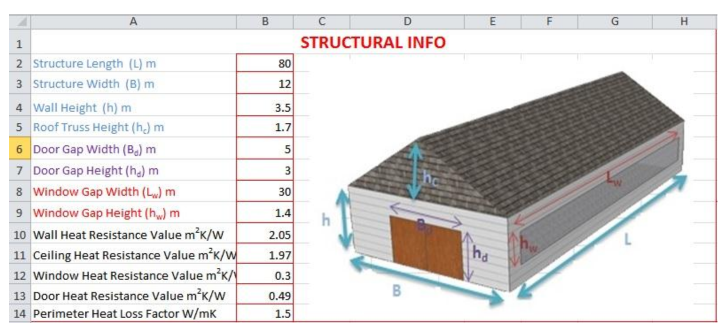

Fig. 1 Structural data input interface

The surface areas of structural components are obtained by the fundamental geometric shape calculations. Then, conductance values (UA) of structural dimensions are calculated.

C. Steady-state energy and mass balances

Ventilation reference worksheet contains measured values of animal heat and moisture production as shown in Table. 1.

TABLE I
ANIMAL HEAT AND MOISTURE PRODUCTION [3]

	Temp. (^{0}C)	MP[a] mg/kg s	LHP[b] W/kg	SHP[c] W/kg	THP[d] W/kg
Dairy Cow 500kg	-1	0.21	0.5	1.9	2.4
	10	0.28	0.7	1.5	2.2
	15	0.36	0.9	1.2	2.1
	21	0.36	0.9	1.1	2
	27	0.5	1.3	0.6	1.9

[a]MP = moisture production, [b]LHP = latent heat production, [c]SHP = sensible heat production, [d]THP = total heat production

With the reference values taken from Table I; moisture, latent heat, sensible heat and total heat production values are calculated. Finally, output cells present followings;

- Total moisture production
- Air moisture content
- Total sensible animal heat production
- Perimeter heat loss conductance

D. Ventilation rates

For naturally ventilated barns, system design based on energy balance, moisture balance and CO_2 balance (2)-(4).

According to energy balance;

$$\tilde{V}_{temp}= [q_s\text{-}(\sum UA+FP)(t_i\text{-}t_o)]/1006\rho(t_i\text{-}t_o) \qquad (2)$$

where:

q_s= total sensible animal heat production (W);
t_i= indoor dry-bulb temperature (^{o}C);
t_o= outdoor dry-bulb temperature (^{o}C);
FP= perimeter heat loss factor (W/K);
ρ= density (kg/m^3).

According to moisture balance;

$$\tilde{V}_{H2O}= Mp/\rho_{air}(Wi\text{-}Wo) \qquad (3)$$

where:

ρ_{air}= air density (kg/m^3);
Wi= indoor air humidity (kg/kg);
Wo= outdoor air humidity (kg/kg).

According to CO_2 control;

$$\tilde{V}_{CO2}= (CO_2)_p/[(CO_2)_i\text{-}(CO_2)_o] \qquad (4)$$
$$(CO_2)_p=THP.AU/1000$$

Various ventilation rates are determined for significant outdoor temperatures (-25, -20, -15, -10, -5, 0, 5 ^{o}C) with an embedded macro according to energy balance, moisture balance and CO_2 control.

Resulting rates marked on a two-axis diagram (Fig. 2).

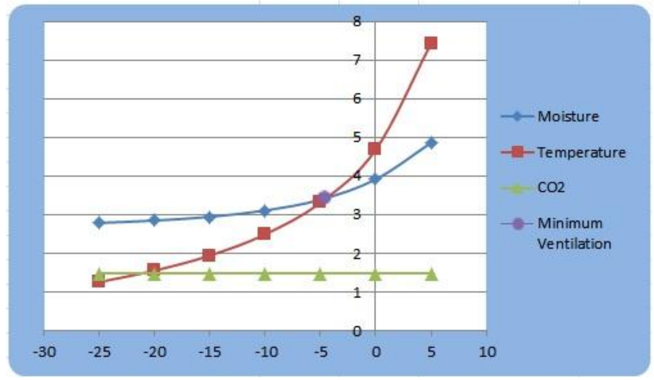

Fig. 2 Ventilation curves for varying outdoor temperatures

Polynomial regression macro module determines the intercept of the moisture and temperature curves (Fig 3).

```
' Find the point where two segments
intersect.
Public Sub
FindLineIntersection( _
ByVal x11 As Single,
ByVal y11 As Single, _
ByVal x12 As Single,
ByVal y12 As Single, _
ByVal x21 As Single,
ByVal y21 As Single, _
ByVal x22 As Single,
ByVal y22 As Single, _
ByRef inter_x As Single,
ByRef inter_y As Single,
_
ByRef inter_x1 As Single,
ByRef inter_y1 As Single,
_
ByRef inter_x2 As Single,
ByRef inter_y2 As Single)
Dim dx1 As Single
Dim dy1 As Single
Dim dx2 As Single
Dim dy2 As Single
Dim t1 As Single
Dim t2 As Single
Dim denominator As
Single
' Get the segments'
parameters.
dx1 = x12 - x11
dy1 = y12 - y11
dx2 = x22 - x21
dy2 = y22 - y21
' Solve for t1 and t2.
On Error Resume Next
denominator = (dy1 * dx2
- dx1 * dy2)
t1 = ((x11 - x21) * dy2 +
(y21 - y11) * dx2) / _
denominator
If Err.Number <> 0 Then
' The lines are parallel.
inter_x = 1E+38: inter_y =
1E+38
inter_x1 = 1E+38:
inter_y1 = 1E+38
inter_x2 = 1E+38:
inter_y2 = 1E+38
Exit Sub
End If
On Error GoTo 0
t2 = ((x21 - x11) * dy1 +
(y11 - y21) * dx1) / _
-denominator
' Find the point of
intersection.
inter_x = x11 + dx1 * t1
inter_y = y11 + dy1 * t1
' Find the closest points on
the segments.
If t1 < 0 Then
t1 = 0
ElseIf t1 > 1 Then
t1 = 1
End If
If t2 < 0 Then
t2 = 0
ElseIf t2 > 1 Then
t2 = 1
End If
inter_x1 = x11 + dx1 * t1
inter_y1 = y11 + dy1 * t1
inter_x2 = x21 + dx2 * t2
inter_y2 = y21 + dy2 * t2
End Sub
```

Fig. 3 Polynomial regression macro module codes

Y-axis value of the intercept point represent minimum ventilation rate [3].

Air inlet and discharge opening dimensions are determined according to minimum ventilation rate [6]. The Fig. 4 demonstrates general ventilation design including two fresh air inlets beneath the eaves and one discharge opening top of the ridge.

Fig. 4 Natural ventilation design

As a result, discharged air amount from the ridge opening must be equal to total air-stream from both eave openings.

E. Temperature-humidity Index

THI indicator schema represents livestock comfort grade depend on desired indoor environment conditions (5).

THI equation;

$$THI= t_i+(0.36t_d)+41 \tag{5}$$

where:

t_i= indoor temperature (^oC);
t_d= dew point temperature (^oC).

Stress categories according to equation results are:

- 0 to 72 Stress-free;
- 72 to 79 Alarm;
- 79 to 89 Danger;
- 89 to 97 Emergency;
- Beyond 97 Fatal.

Extreme values for the stress categories determined based on dry-bulb temperature and dew point results [7][8]. Five stress categories (stress-free, alarm, danger, and emergency, fatal) appears in its own and precautions also appears in its own cell. Early studies emphasize the relationship between milk productivity and the THI change [2]. Herbut and Angrecka studied out a decrease of mean 3.5 kg milk production as a result of THI values around 80 [2].

F. Procedure

Procedure be formed as 4 (Psychometric reference, ventilation reference, psychrometrics and ventilation) worksheets. Table I. procure correlation values to output cells in the reference worksheets. Data flow provides between reference worksheets and the "Ventilation" worksheet that is user interface (Fig. 5).

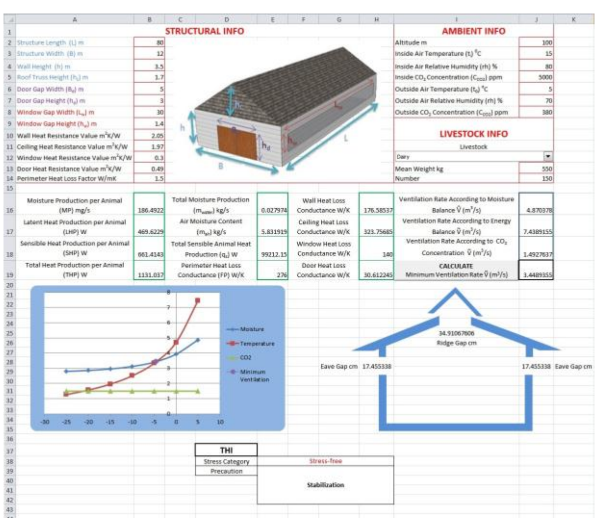

Fig.5 User interface

Formulated procedure outputs update in real-time according to structural, ambient and livestock data which are given by the end user in the red framed cells.

"Calculate minimum ventilation rate" button can be operated only if the THI indicator show convenient stress category. The installed macro modules plot the ventilation curves and minimum ventilation rate appears in the cell next to the button. The figure demonstrates the required ridge and eaves opening dimensions placed next to ventilation diagram simultaneously.

III. Results and Discussion

Monitoring stress status on dairy cows is essential for a profitable production. However, dynamic ambient conditions are obstructing the process. Various parameters which are required to determine the indoor comfort level can be calculated by psychometrics. Psychometrics is formed as progressive steps and time-consuming process prevents real-time calculations. With the procedure inside the worksheet, every parameter can be sustained simultaneously. Stabilizing the indoor air quality is another consideration for the dairy barns. Ventilation rate has to be arranged based on psychometrics and balanced according to variables such as indoor humidity, temperature and CO_2 concentration. Three different variables provide three different ventilation rates. Therefore, an iterative calculation needed for specify the minimum ventilation rate. This is also a time-consuming stage for calculations.

Commercial barns must be planned professionally on first establishing stage and also be able to future expansions. Ventilation openings are significant part of planning. Nevertheless, the correct equation alignment needed for a successful investment. So the procedure provides the right opening gaps for the input dimensions.

Barn indoor ambient conditions affect the animals' comfort levels. Therefore, production capacity decreases. Animal originated moisture and heat production accumulates in the structure under insufficient ventilation conditions. Vice versa, heavy ventilation can lead energy loss and increase feeding expenses. THI is essential for optimizing the animals' comfort grade and lower business expenses [2].

Determining the animals stress levels according to THI is an everlasting and complicated operation for the producers. This procedure shortens and eases the workload on calculations.

Procedure worksheet is open source software and can be modified on that sense. For future research, forming the procedure as software using a programming language like C++, Java, etc. makes it more user-friendly and handy. Also, it can be adapted to various operating systems with an appropriate runtime module. Next stage for developing the procedure may lead for an automated ventilation system. Fixed sensor systems can provide the real-time signals for the system and software output orient the step motor assisted ventilation panes.

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