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MODELLING OF THE TEMPERATURE-HUMIDITY INDEX (THI) AND VENTILATION PATTERNS IN THE RABBITS' PENS

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Abstract
The research developed a model for the prediction of the Temperature-Humidity Index (THI) inside the rabbits' pen resulting from combined effects of ventilation openings and building orientations on the performance of rabbit does. Three factors were considered in the study, namely; different seasons of the year (dry and rainy seasons), building orientations (45^o and 90^o to the directions of the prevailing wind) and ventilation openings (20%, 40%, 60% and 80% side openings). The experimental set up was a 2 x 2 x 4 completely randomized block design with the effect of orientation and ventilation openings investigated during the dry and rainy seasons, each treatment was replicated four times. Monitoring of the internal environmental parameters (temperature, relative humidity, THI_{in} and ventilation rate) of the building was done when the building was stocked. The measurements were taken twice daily at 08.00h and 14.00h during both seasons. The maximum absolute difference in the prediction of the ventilation rate was 1.94 x 10^{-3} m^3/s in the 90^o orientation during the rainy season and 4.8 x 10^{-3} m^3/s in the 45^o orientation during the dry season. The predicted values were approximated closely to the observed values at $p \leq 0.05$. There was no significant difference ($p \geq 0.05$) between the observed and predicted values. Therefore, the model predicted is valid and appropriate for the THI and the ventilation rates in the rabbit pens.

Key Words: *Doe, Opening, Stocked, Ventilation rate, Orientation*

Introduction

The location of a building should be able to induce air movement into the building. It should be able to minimize adverse air movement, especially the undesirable odour that should not be allowed inside the building by closing the direction where such undesirable odour may come (Boutet, 1987). Also, the location of a building must minimize energy consumption and possibly save cost without undermining its usefulness. Air movement around a building may be two to three times greater than the free-flow air velocity, this will help in the planning, as the need be inside the

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building, also the size and number of its openings should be designed (Lamidi, 2011). Buildings should not be oriented for a particular air movement direction only; they should be designed for effective air movement in prevailing directions, as the orientation of building could influence the location of inlet and outlet openings of air. Thus, it influences the leeward and the windward sides of the building (Tom, 2008; Nicol, 2004; Bruce, 1982). When the building opening is 'direct' to the direction of the prevailing wind, air pressure is positive on the windward side of the building and this results in an inflow of air into the building (Pennington and VanDevender, 2010). Similarly, the air pressure is negative on the leeward side of the building, this results in an outflow of air from the building and with these two, the highest air movement around the building happens in the windward vortex and the corners (Lamidi *et al.,* 2015; Givoni, 2007).

The objective of the research was to develop a model for the prediction of the Temperature-Humidity Index (THI) inside the rabbits' pen resulting from combined effects of ventilation opening and building orientation on the performance of does.

Materials and Methods

Experimental Site

The study was carried out in a rabbitry on a research farm in a serene, calm environment in Okinni community- an outskirt of Osogbo, a city in the rain forest zone of Nigeria. Osogbo is on latitude 7.842° N and longitude 4.536° E, (Figure 1). Four identical buildings with dimensions 1.2 m × 4.8 m × 1.2 m (width × length × height, respectively) were constructed. Other specifications of the building included floor area per pen (1.2 m x 0.6 m), building length and width respectively 4.8 m and 1.2 m, 30^{o} roof slope and wall height (1.95 m). The building was opened at 20% or 40% or 60% or 80% on windward long sides as the inlet and at 20% outlet leeward side. Another smaller building housing rabbit at the same farms was used as control building. It was appropriate because it is similar to the existing rabbit building of the Obafemi Awolowo University Teaching and Research farm in Ile-Ife, Nigeria. The research was based on earlier experiment done in Obafemi Awolowo University, Ile-Ife Teaching and Research Farm. This fits in because the house is 100% open at all sides, with the length 10 m and breadth 10 m. There were four rows of pens that ran across the lengths of the building at height 0.75 m up the concrete floor.

Fig. 1: Place where the experiment was conducted

Research Design and Experimentation

Three factors were considered in the study: different seasons of the year (dry and rainy seasons); building orientations (45^o and 90^o to the directions of the wind) and ventilation openings (20%, 40%, 60% and 80% side openings). The experimental set up was a 2 x 2 x 4 completely randomized block design with the effect of orientation and ventilation openings investigated during the dry and rainy seasons, each treatment was replicated four times. The experiment was carried out between November and March for the first two parities for dry season and between May and September for the rainy season two parities.

Each building with eight pens was constructed with consideration to the orientation to be tested. There were two phases in the experimental measurement; the first phase was the monitoring of the prevailing outside weather parameters (wind direction, speed, temperature, relative humidity). The second phase involved measuring/computation of the internal environmental parameters (temperature, relative humidity, THI and ventilation rate) of the building when the building was stocked. The measurements were taken twice daily at 08.00h and 14.00h during both seasons.

Experimental modelling for THI inside the pens

Consider an opening in a vertical pen of the building (free body diagram in Figure 2) in which the air density (ρ_i) inside the pen was lower than the outside air density (ρ_o). If there is a neutral plane y of height, h, from the floor of the pen of which there was no pressure differential either to gravity or to buoyancy effect, then

$P_o(y) = P_i (y)$ … … (1)

where

P_o = outside pressure and P_i = pressure inside the pen

At height 'z' from the pen floor, the pressure difference (ΔP), in kg/ms^2 was

$\Delta P (y) = g (\rho_o - \rho_i) (y - z)$ … (2)

where

g = acceleration due to gravity, m/s^2 and y –z is difference in height

From Figure 2,

l = length of the pen, metres; b = width of the pen, metres and

l_c = local loss coefficient for material of construction, dimensionless

For wire net, l_c = 1; for wood, l_c = 1.2 and for wall, l_c = 1.5; [ASAE,1999 ; Bruce, 1999]. Wire net was used for the openings.

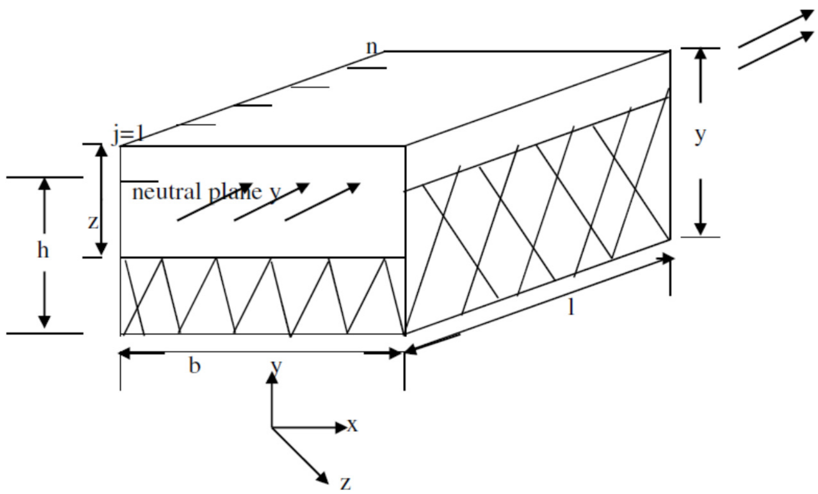

Fig. 2: Free body diagram showing inlet and outlet sides of the vertical pen of the building with neutral plane y.

From equation 2, assuming ΔP was available to overcome resistance to the airflow and also to provide kinetic pressure in the pen, then we have

$$\Delta P(y) = \{f\frac{l}{b} + \sum l_c\}\ \rho\, v^2/2 \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \qquad (3)$$

where f = frictional factor, dimensionless

ρ = density of the air in kgm^{-3}

v = velocity of the air, ms^{-1}

Equating equations 2 and 3;

$$g\,(\rho_o - \rho_i)(y - z) = (f\frac{l}{b} + \sum l_c)\ \rho\, v^2/2 \quad \dots \quad \dots \quad \dots \qquad (4)$$

Solving for velocity in the equation 4, we have

$$v = \frac{|y-z|}{(y-z)}\{2g\ \frac{\Delta\rho}{\rho}\ |y - z| \Big/ (f\frac{l}{b} + \sum l_c)^{½}\} \quad \dots \quad \dots \quad \dots \qquad (5)$$

The heat transfer equation and continuity in mass flow show that when density was constant, the mass flow is constant, that is, where Q is the ventilation rate at area A within the pen

$$\sum_{j=1}^{n}\int_{Aj}\rho v dA = Q \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \qquad (6)$$

Substituting equation (5) in (6);

$$\{2g\ \frac{\Delta\rho}{\rho}\}\ \sum_{j=1}^{n}\ (f\frac{l}{b} + \sum l_c)^{-½}\ \int_{Aj}\frac{|y-z|^{3/2}}{(y-z)}dA = Q \quad \dots \quad \dots \qquad (7)$$

Since air density $\Delta\rho/\rho$ can be replaced by ΔT/T when air is treated as perfect gas at approximately constant pressure and small ΔT, also since n =1 for a pen, we then have

$$Q = \{2g \frac{\Delta T}{T}\} \sum(f\frac{l}{b} + \sum l_c)^{-½} \int_{Aj} \frac{|y-z|^{3/2}}{(y-z)} dA \quad \ldots \quad \ldots \quad (8)$$

$$Q = \{2g \frac{\Delta T}{T}\} \{f\frac{l}{b} + \sum l_c\}^{-½} \int_{Aj} \frac{|y-z|^{3/2}}{(y-z)} dA \ldots \quad \ldots \quad \ldots \quad (9)$$

From the relationship, equation 10,

$$\int (a-y)^p (a-y)^q dy = \frac{1}{p+q+1} |a-y|^p |a-y|^{q+1} \quad \ldots \ldots \quad \ldots \quad (10)$$

$$\text{if} \quad p+q ‡ -1$$

Applying equation (10) to (9), we have,

$$Q = \{2g \frac{\Delta T}{T}\} \sum\{f\frac{l}{b} + \sum l_c\}^{-½} \frac{2A}{3} (y-z)^{2'} \quad \ldots \quad \ldots \quad \ldots \ldots \quad (11)$$

The chicken wire net has frictional factor zero to the wind and since there was just an opening in the pen in consideration, $\sum l_c = l_c$; therefore,

$$Q = -\{2g \frac{\Delta T}{T}\} l_c^{-½} \frac{2A}{3} (y-z)^2 \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (12)$$

From symmetry, the effect of the wind is felt more at

$y = z/2$ … … … … … … … … (13)

then $Q = -\{2g \frac{\Delta T}{T}\} l_c^{-½} \frac{2A}{3} \left(\frac{z}{2} - z\right)^2$ … … … … (14)

solving;

$$Q = \frac{A}{3} \{gz \frac{\Delta T}{T}\} l_c^{-½} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (15)$$

Solving equation 15 for Q, $l_c = 1$ for wire net; the equation now reduced to

$$Q = \frac{A}{3} \frac{\Delta T}{T} [g z]^{1/2} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (16)$$

Equation (16) gives the ventilation rate, m^3s^{-1}, inside the pen, at a particular time in seconds. Rewriting equation 15, as ΔT turns to zero, it becomes dT and with changes in the rate of ventilation from a point to the other inside of the pen, then,

$$dQ = \frac{A}{3} [gz]^{1/2} . \frac{dT}{T} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (17)$$

if $\frac{A}{3}$ $[gz]^{1/2}$ is now constant k of the product of some parameters of the pen as shown

(area, A; height of opening to the ground, z and acceleration due to gravity, g), integrating with the limit T_o (immediate outside temperature) and T_1 (inside temperature),

$$Q = -\frac{1}{2} k \ln \frac{T_O}{T_1} + c \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (18)$$

where

$$k = \frac{A}{3} [gz]^{1/2} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (19)$$

Q = is the slope of the graph of ventilation against the natural logarithm of fraction of the temperature inside the pen to the temperature at the immediate outside of the pen, g = acceleration due to gravity, m^2/s; z = height of the opening of the pen and c = constant.
From equation 16,

$$Q = k\ (T_1 - T_0)\ /\ T_1 \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \qquad (20)$$

$$T_1 = \frac{kT_0}{(k-Q)} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \qquad (21)$$

Marai *et al.,* (2001) gave THI equation as

$$THI = t_{db} - [0.31(1 - \left[\frac{RH}{100}\right])](t_{db}\ \text{-14.4})\} \quad \ldots \quad \ldots \quad \ldots \qquad (22)$$

where t_{db} = dry bulb temperature, °C and RH = relative humidity, %
Substituting equation 21 in equation 22, replacing t_{db} with T_1

$$THI = \frac{kT_0}{(k-Q)} - \{[0.31 - 0.31\left[\frac{RH}{100}\right]](\frac{kT_0}{(k-Q)}\ \text{-14.4})\} \quad \ldots \qquad (23)$$

Factorising

$$THI = \frac{kT_0}{(k-Q)} - [(0.31(1 - \left[\frac{RH}{100}\right]](\frac{kT_0}{(k-Q)}\ \text{-14.4})\} \quad \ldots \qquad (24)$$

where $$T_0 = \frac{T_1(k-Q)}{k} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \qquad (25)$$

k, Q and T_o and T_1 are defined above

Result and Discussion

Theoretical Prediction of the THI in the Pens

The modelling equation (Equation 24) was used to find its fitting with the observed THI data. The results of the calculated (observed) values of the Temperature-Humidity Index (THI) in ^{0}C using the equation 24 were compared using paired t-test (SAS, 2008). The test showed that none of the measured and the predicted data for the THI and by extension the Q for the openings or the orientation was significant, revealing that the model was well fitted for the experiment. Tables 1 and 2 showed the summary of the results of modelling at both orientations and at all the openings for the dry and rainy seasons. The results revealed that the model was fitted for all the openings in both dry and rainy seasons except for 20% opening in both seasons, openings 40% at 45° orientation in the dry season and openings 20% at 90° orientation, 60% at 90° orientation and 80% at 45° orientations in the rainy season.

Tables 3 and 4 showed the summary of the order of ranking of the results of modelling for the dry and rainy seasons. The ranking revealed that the ventilation rate, Q ranged from 3.30 x 10^{-3} m^3s^{-1} to 5.77 x 10^{-3} m^3s^{-1} throughout the conception and post-natal periods in the dry season and 2.4 x 10^{-4} m^3s^{-1} to 4.92 x 10^{-3} m^3s^{-1} in the rainy season. Openings 100% and 80% at 90° were the highest ventilated pens respectively during the dry and rainy seasons with values 5.77 x 10^{-3} and 4.92 x 10^{-3} m^3s^{-1}.

The rankings in Tables 3 and 4 showed that opening 80% at 90° orientation and

60% at 90° orientations respectively had R^2 values of 0.94 and 0.84. The highest R^2 value of 0.97 was obtained for opening 80% at 90° orientation in the rainy season, this showed high correlation among the ventilation rate and THI in the pen and the openings and orientations of the building and their effect on the reproductive performances of rabbits (Lamidi, 2011). The higher R^2 values recorded for the pens showed that the predicted values were approximated closely to the observed values at $p \leq 0.05$. Also, the standard deviations recorded for dry and rainy seasons were low, this showed that the Q and THI values were close to each other in the dry season than in the rainy season.

Validation of Model predicting THI in different openings and orientations

The model described by Chen *et al*., (2002a, 2002b and 2004) were used in comparisons of the observed and modelled data from each of the ten operating points at both orientations. For each of the dry and rainy seasons, Q and THI are shown in Tables 5 and 6 respectively for 45° and 90° orientations. THI model showed that it predicted the temperature inside the pen, T_1 and its RH (relative humidity) very well (Equations 24 and 25).

For each of the ten operating points at both 45° and 90° orientations in each season, the maximum relative error was 1.98 °C for the THI in the rainy season at 90° orientation, Table 6; and 1.80 °C in the 45° orientation during the dry season, Table 5.

Table 1: Summary of the results of modelling of THI, Q, in dry season
n = gestation + post natal days =70 days

Treatment	Model parameters		R^2	Paired sample t-test		
	Q (m^3/s)	THI		Rm(%)	б	p-values
Opening, Op; Orientation, Or						
Op 20.45 Or	0.00283	26.66	0.84	26.04	2.7897	0.571
Op 40.45 Or	0.00278	25.32	0.89	26.18	2.0369	0.511
Op 60.45 Or	0.00330	28.40	0.95	26.04	2.2899	0.262
Op 80.45 Or	0.00303	24.56	0.93	26.18	2.4079	0.440
Op 20.90 Or	0.00299	25.81	0.97	26.38	2.6448	0.062
Op 40.90 Or	0.00286	26.23	0.84	26.04	2.0700	0.834
Op 60.90 Or	0.00279	27.55	0.97	26.05	2.2951	0.290
Op 80.90 Or	0.00417	27.48	0.94	26.04	2.3520	0.340
100%	0.00577	27.37	0.93	26.21	2.2668	0.176
Orientation, Or						
45⁰	0.00268	24.96	0.79	26.21	2.2668	0.051
90⁰	0.00275	27.27	0.80	26.04	2.2174	0.084
Opening, Op						
20%	0.00283	27.04	0.95	26.04	2.2899	0.262
40%	0.00166	28.40	0.90	26.30	1.6258	0.162
60%	0.00284	26.00	0.97	26.81	2.2800	0.668
80%	0.00300	26.07	0.94	26.12	2.3811	0.442

Table 2: Summary of the results of modelling of THI, Q, in rainy season
n = gestation + post natal days =70 days

Treatment	Model parameters		R^2	Paired sample t-test		
	Q (m^3/s)	THI		Rm(%)	б	p-values
Opening, Op; Orientation, Or						
Op 20.45 Or	0.00127	26.86	0.92	30.84	2.6668	0.076
Op 40.45 Or	0.00024	25.54	0.82	30.95	1.0362	0.176
Op 60.45 Or	0.00201	25.44	0.95	30.93	3.0232	0.571
Op 80.45 Or	0.00492	26.65	0.92	31.31	3.0079	0.576
Op 20.90 Or	0.00177	24.81	0.88	30.91	3.0087	0.081
Op 40.90 Or	0.00062	24.32	0.95	30.99	3.2241	0.052
Op 60.90 Or	0.00427	25.45	0.85	30.99	3.2465	0.606
Op 80.90 Or	0.00398	25.80	0.97	30.78	3.9052	0.715
100%	0.00307	26.46	0.30	30.99	3.0682	0.115
Orientation, Or						
45^0	0.00166	24.36	0.88	30.21	3.0969	0.060
90^0	0.00100	25.67	0.90	31.00	1.2170	0.080
Opening, Op						
20%	0.00015	26.40	0.83	30.54	2.2899	0.089
40%	0.00166	25.40	0.87	30.95	2.6840	0.052
60%	0.00400	25.00	0.87	31.08	2.2708	0.817
80%	0.00500	26.07	0.99	32.94	2.3021	0.576

Table 3: Summary of the ranking order of modelling result during dry season

Treatment	Q (m^3/s)	Treatment	THI	Treatment	R^2	Treatment	б
100%	0.00577	Op 60.45 Or	28.40	Op 80.90 Or	0.94	Op 20.45 Or	2.7897
Op 80.90 Or	0.00417	Op 60.90 Or	27.55	Op 60.45 Or	0.89	Op 20.90 Or	2.6448
Op 80.45 Or	0.00303	Op 80.90 Or	27.48	Op 80.45 Or	0.89	Op 80.45 Or	2.4079
Op 20.90 Or	0.00299	100%	27.37	Op 20.90 Or	0.88	Op 80.90 Or	2.3520
Op 40.90 Or	0.00286	Op 20.45 Or	26.66	Op 60.90 Or	0.84	Op 60.90 Or	2.2951
Op 20.45 Or	0.00283	Op 40.90 Or	26.23	Op 20.45 Or	0.83	Op 60.45 Or	2.2899
Op 60.90 Or	0.00279	Op 20.90 Or	25.81	Op 40.45 Or	0.79	100%	2.2668
Op 40.45 Or	0.00278	Op 40.45 Or	25.32	Op 40.90 Or	0.75	Op 40.90 Or	2.0700
Op 60.45 Or	0.00330	Op 80.45 Or	24.56	100%	0.14	Op 40.45 Or	2.0369

Table 4: Summary of the ranking order of modelling result during rainy season

Treatment	Q (m^3/s)	Treatment	THI	Treatment	R^2	Treatment	б
Op 80.90 Or	0.00492	Op 20.45 Or	26.86	Op 80.90 Or	0.97	Op 60.90 Or	3.2465
Op 60.90 Or	0.00427	Op 60.45 Or	26.65	Op 60.45 Or	0.95	Op 40.90 Or	3.2241
100%r	0.00398	100%r	26.46	Op 40.90 Or	0.95	100%	3.0682
Op 80.45 Or	0.00207	Op 80.90 Or	25.80	Op 20.45 Or	0.92	Op 60.45 Or	3.0232
Op 60.45 Or	0.00201	Op 40.45 Or	25.54	Op 80.45 Or	0.92	Op 60.90 Or	3.0087
Op 20.90 Or	0.00177	Op 60.90 Or	25.45	Op 20.90 Or	0.88	Op 80.45 Or	3.0079
Op 20.45 Or	0.00127	Op 60.45 Or	25.44	Op 60.90 Or	0.85	Op 80.90 Or	2.9052
Op 40.90 Or	0.00062	Op 20.90 Or	24.81	Op 40.45 Or	0.82	Op 20.45 Or	2.6668
Op 40.45 Or	0.00024	Op 40.90 Or	24.32	100%	0.30	Op 40.45 Or	1.0362

Table 5: Comparison of the measured (observed) and calculated (predicted) data at 45° orientation in dry and rainy seasons

Parameters	Season	Decision	Opening, Op, %				
			20	40	60	80	100
Q (m^3/s)	Dry	Observed	0.00283	0.00278	0.00130	0.00303	0.00577
		Predicted	0.00185	0.00300	0.00298	0.00200	0.00660
		Error	0.00098	0.00022	0.00320	0.00103	0.00083
	Rain	Observed	0.00127	0.00240	0.00201	0.00307	0.00398
		Predicted	0.00099	0.00380	0.00460	0.00259	0.00185
		Error	0.00028	0.00140	0.00259	0.00480	0.00213
THI	Dry	Observed	26.66	25.32	28.40	24.56	27.37
		Predicted	26.42	26.02	27.60	25.10	26.80
		Error	0.24	0.70	1.80	0.54	0.57
	Rain	Observed	26.86	25.54	25.44	26.65	26.46
		Predicted	26.20	25.00	24.60	25.90	25.80
		Error	0.06	0.84	0.84	0.75	0.66

Table 6: Comparison of the measured (observed) and calculated (predicted) data at 90° orientation in dry and rainy seasons

Parameters	Season	Decision	Opening, Op, %				
			20	40	60	80	100
Q (m^3/s)	Dry	Observed	0.00299	0.00286	0.00279	0.00417	0.00608
		Predicted	0.00213	0.00298	0.00460	0.00281	0.00560
		Error	0.00086	0.00012	0.00181	0.00136	0.00048
	Rain	Observed	0.00177	0.00162	0.00427	0.00492	0.00398
		Predicted	0.00285	0.00108	0.00476	0.00298	0.00294
		Error	0.00108	0.00054	0.00049	0.00194	0.00104
THI	Dry	Observed	25.81	25.23	27.55	27.48	27.37
		Predicted	26.70	27.80	27.20	27.00	26.00
		Error	0.91	1.57	0.35	0.48	1.05
	Rain	Observed	24.81	24.32	25.45	25.80	26.46
		Predicted	25.20	26.30	26.40	27.20	27.31
		Error	0.39	1.98	0.95	1.40	0.85

The Q values for both orientations cross respectively at building openings between 40 and 60% and at between 60 and 80% (at 70%) respectively with the values of just below and above 0.003 m^3/s. At both seasons, the Q fluctuates in both orientations in the experiment showing that the effect of the different openings on the pen's inside conditions and the rabbits therein.

Experimental data showed that the THI values for both orientations cross respectively at building openings 30% (between 20 and 40%) and 50% (between 40 and 60%) with the values of 25.8 and 26.81 ^oC according to Table 6 and 27.55 ^oC between 60 and 80% openings. In the 90^o orientation, the THI values for both orientations cross respectively at 60% building opening with the values of 25.5 ^oC and 26.3 ^oC at 100%. The THI of the pen decreases as the building opening increases from 20% and more; when the opening was 100%, the THI decreases to 26.40 ^oC in the 45^o orientation, the same for the 90^o orientation, even more pronounced. This may be because of the normal wind direction, that is, 90^0 to the direction of the prevailing wind.

Computation from Results- Input Parameters Used

l_c = frictional factor = 1, for wire net
g = acceleration due to gravity = 9.81 ms^{-2}
A = area of the opening, m^2, to be found.
THI = 27.04 ºC; Temperature = 29.78 ºC; Humidity = 68.60%
Temperature outside T_o = 29.80 ºC; and inside Temperature T_1 = 29.78 ºC
$\Delta T = T_o - T_1$= 0.02 ºC;
z = height of the opening of the rabbit pen = 0.8 m
ρ = air density / (kgm^{-3}) = 1.679 kgm^{-3} at 29.78 ºC
v = air velocity = 0.3532 ms^{-1}
μ = absolute air viscosity Nsm^{-2} = 0.0000246 Nsm^{-2} at 29.78 ºC
ϕ = wind flow angle of incidence = 90 degrees
z/l =ratio of opening height to opening length, dimensionless = 0.8/1.2 = 0.67
θ = roof slope, 30 degrees
Considering the free body diagram Figure 3,

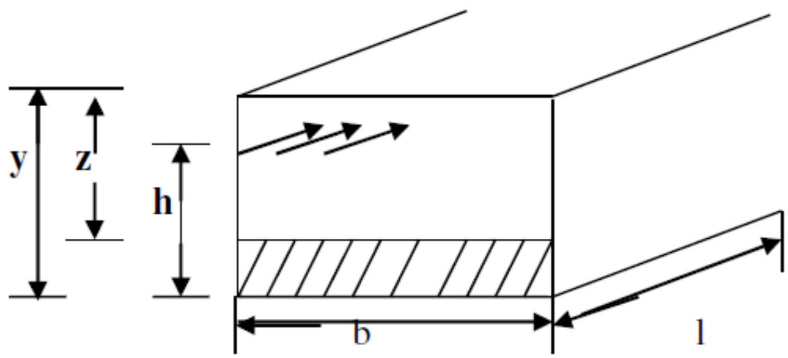

Fig. 3: Free body diagram of opening in windward side

The bases for the design are provided via the ventilation inside the building, the THI inside the pen and the immediate outside of the pen, the roof angle for the building, the area of the opening and the orientation of the building and the design calculations involved. With a pen of width (breadth) b, length l in metres which are unknown,
k = constant of the building and the ventilation opening was 80%, this corresponds to the best ventilation opening got from the research experiment = z = 0.8 m

$$k = \frac{A}{3}[(9.81)(0.8)]^{1/2}$$

$$k = 0.9338A\ m^3s^{-1} \quad \ldots \quad (26)$$

From the predicted equation of THI

$$THI = \frac{kT_0}{(k-Q)} - [(0.31(1-\left[\frac{RH}{100}\right])](\frac{kT_0}{(k-Q)} - 14.4)]$$

Substituting k from equation 26

$$27.04 = \frac{0.9338A\times 29.8}{(0.9338A-Q)} - [(0.31(1-\left[\frac{68.6}{100}\right])](\frac{0.9338A\times 29.8}{(0.9338A-Q)} - 14.4)]$$

$$27.04 = \frac{27.83}{(0.9338A - Q)} - [(0.09734)(\frac{27.83}{(0.9338A - Q)} - 14.4)]$$

Solving, we have

$$25.6383 = \frac{25.121}{(0.9338A - Q)}$$

Solving for Q, we have

$$Q = \frac{23.941A - 25.121}{25.6383} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (27)$$

Also, from the ventilation equation $Q = \frac{A}{3}[g\frac{\Delta T}{T_0}z]^{1/2}$

where A was to be found for the area of the opening in the design; then

$$Q = \frac{A}{3} \times [\frac{9.81 \times 1.4 \times 0.8}{29.8}]^{1/2}$$

$$Q = 0.2024\text{A m}^3\text{s}^{-1} \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (28)$$

Equating equations (27) and (28),

A = 1.32 m^2 and Q = 0.2711 m^3/s

USDAFRD (1992) observed that rabbit needs a minimum of 0.84 m x 0.67 m area, to accommodate the feeding and water troughs in their pens and a maximum of 0.93 m x 0.80 m to accommodate its kits in temperate countries. This predicted model shows that for a rabbits with kits in the tropical region of 30 ^{0}C room temperature, given a space of 0.1 m on either side, then the length × breadth equals 1.20 × 1.10 m^2, at opening height z = 0.8 m, the ventilation inside such pen was 0.2711 m^3s^{-1}.

To estimate the opening effectiveness of the pen E, given by Nasr (1998) as

$$E = 16.33\left[\frac{0.21\rho v}{\mu}\right]^{-0.3515} \text{x Sin}(\phi)^{1.201} \text{ x } \left(\frac{4z}{l}\right)^{-0.1213} \text{x (Sin } \theta)^{-0.1531} \ldots \quad (29)$$

Substituting the values from 3.3 above, we have

$$E = 16.33\left[\frac{0.21 \times 1.562 \times 0.3532}{2.35 \times 10^{-5}}\right]^{-0.3515} \text{x Sin } (90^0)^{1.201} \text{x}\left(\frac{4 \times 0.8}{1.19}\right)^{-0.1213} \text{x (Sin}30^0)^{-0.1531}$$

$$E = 0.789$$

Therefore, the opening effectiveness for a 0.8 m pen's height opening on a building of length = 1.2 m, width =1.1 m and at 30^o roof angle with temperature of 28.4 ^{o}C and air velocity at 0.3532 ms^{-1} was 78.9% and at 90^o building orientation. Both the THI and ventilation equation model had high R^2 value in their polynomial relationships with k, T_o, RH and Q. The THI model showed that it predicted these variables very well because the predicted values were approximated closely to the observed values at $p \leq 0.05$. That is, there was no significant difference between the observed and predicted values. Also, R^2 values were higher as shown in Tables 1-4 signifying that the observed values fit the model and a better fit for the model.

Conclusion

The linear equation model used fitted satisfactorily the observed values and can be used to predict THI values in the building pens at different openings and orientations. The randomised distribution of the calculated residuals showed that the THI values well fitted the model.

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