The Role of Artificial Neural Network (ANN) in Predicting Skin Surface Temperature, Evaporative and Convective Heat Losses from Wet-Skin Surface of a Cow

Zahid A. Khan, G.A. Quadir, Arif Suhail & K.N. Seetharamu

ABSTRACT

A multi-layered feedforward fully-connected Artificial Neural Network (ANN) based on Levenberg-Marquardt training algorithm is used to predict skin temperature, evaporative and convective heat losses from a cow. The mathematical model available in the literature is used to generate training data to train the neural network. The predicted skin temperatures, evaporative and convective heat losses due to the change in level of wetness, air velocity, relative humidity and ambient air temperature using ANN agree very closely with those obtained from the mathematical model used in the analysis.

Keywords: *Artificial Neural Network; Heat Stress; Evaporative cooling; Convective cooling; Fur layer*

Introduction

It has been reported that one of the major factors which adversely affect milk production of dairy cows is the thermal environment [1]. The milk production and breeding efficiencies of cows reduce significantly due to severe heat stress caused by hot and humid environments [2]. Stowell [3] has reported that without supplemental cooling, drops in milk yield of 20-30% following hot, muggy stretches are not uncommon in high-producing herds. A common and effective method to cool off cows is sprinkling water on them and promoting its rapid evaporation [4], [5], [2]. It is believed that when the animal is wet then moisture and heat flow takes place much more quickly through a hair coat that has been wetted to the skin [6]. Gebremedhin and Wu [2] have suggested that the evaporative cooling is further accelerated by blowing air over it. The water vapour moves very slowly under still-air conditions but moves faster with increasing air velocity, and allows moisture to continue evaporating from the wet skin surface and fur layer. The air around the cow is replaced with fresh air due to natural air movement or ventilation and thus, allows more moist air to be withdrawn from the hair coat. Gebremedhin and Wu [2] took into account this process of cooling and developed an iterative mathematical model using fluid flow and heat and mass transfer equations to predict skin temperature, evaporative and convective heat losses from the wet-skin surface of cows. The mathematical model proposed by them is a bit complex and in order to use it, the users must have an understanding of heat and mass transfer concepts in addition to computer programming skills. Thus, there is a need for a simplified method to solve this problem. From the literature, it has been found that ANN have been successfully applied to a variety of function approximation or classification problems [7]. The objective of this paper is to present a simplified method to predict these parameters for different environmental and skin wetness condition using Artificial Neural Network (ANN). The trained ANN can be used by any user without any difficulty to predict skin temperature, evaporative and convective heat losses. The mathematical model of Gebremedhin and Wu [2] is used in the present analysis with the same assumptions and values of fixed parameters like weight and diameter of the cow, hair coat thickness, hair density, fur density, internal body temperature, thermal conductivity of fur layer, Prandtl number, etc. as the basis to provide the initial data for training ANN.

Analysis

Gebremedhin and Wu [2] have represented the cow as a cylinder with an internal heat source. The flow field between the animal and the environment is divided into laminar boundary layer and the turbulent boundary (convective) layer as shown in Figure 1. The laminar boundary layer consists of sum of the thickness of fur layer (δ_1) and a thin film of air layer (δ_2) above it. The full details of their mathematical model can be found in their paper [2]. However, some related assumptions and governing equations are reproduced here for the purpose of completeness. The assumptions used in their model are given below:

(1) Animal geometry is represented by a cylinder.
(2) Flow, heat and mass, is assumed to be steady state.
(3) Thermal properties are assumed to be constant.
(4) Air flow within the hair coat is assumed to be laminar.
(5) The internal body temperature is assumed to be constant.
(6) Laminar boundary layer includes the fur layer and a thin film of air layer outside the hair coat. Heat conduction and molecular diffusion are considered in this layer.
(7) Mass diffusion coefficient of water vapour is assumed to be constant in the laminar boundary layer.

(8) In the turbulent boundary layer, only convective heat and mass transfer are considered.

(9) Radiant heat exchange between the subject and its surrounding is not considered in this study.

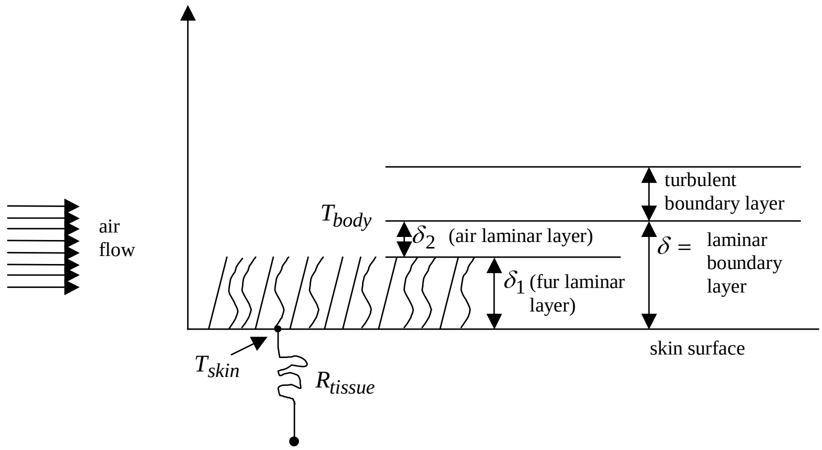

Figure 1: Schematic Diagram Showing Laminar and Turbulent Boundary Layers within the Fur Layer (Gebremedhin and Wu, 2001)

The governing equations of their model are given below:

$$Q_{total} = Q_{evap} + Q_{conv} \tag{1}$$

$$Q_{evap} = \lambda j \beta A_s \tag{2}$$

$$j = (C_{skin} - C_o) \Big/ \left(\frac{1}{h_m} + \frac{\delta_1 + \delta_2}{D} \right) \tag{3}$$

$$Q_{conv} = (T_{skin} - T_a) A_s \Big/ \left(\frac{1}{h_c} + \frac{\delta_1}{k_{eff}} + \frac{\delta_2}{k_{air}} \right) \tag{4}$$

$$Q_{total} = A_s (T_{body} - T_{skin}) / R_{tissue} \tag{5}$$

The symbols used in the above equations have the following meaning:

Q_{total} - Total heat loss from the animal (W), which is sum of evaporative (Q_{evap}) and convective (Q_{conv}) heat losses (W).

λ - Latent heat of vapourisation of water at the skin-surface temperature (kJ/kg water).

j - Total mass flux of water vapour (kmol/m^2 s).

β - Percent wet area of the skin surface (%).

A_s - Surface area (m^2) which is a function of the weight of the animal (W) as 0.15 $W^{0.56}$.
C_{skin} - Concentration of water vapour on the skin surface (kmol/m^3).
C_o - Concentration of water vapour in the ambient air (kmol/m^3).
h_m - Convective mass transfer coefficient (m/s).
D - Mass diffusive coefficient of water vapour (m^2/s).
T_{skin} - Skin surface temperature (K or °C).
T_a - Ambient air temperature (K or °C).
h_c - Convective heat transfer coefficient (W/m^2 K).
k_{eff} - Mean effective thermal conductivity of the fur layer (W/m^2 K).
k_{air} - Thermal conductivity of the ambient air (W/m^2 K).
T_{body} - Average internal body temperature (K or °C).
R_{tissue} - Heat resistance of tissue (m^2 K/W).

Combining equations (2), (4), and (5), Q_{evap}, Q_{conv}, and T_{skin} are solved by iteration. The details of evaluating C_{skin}, C_o, h_m, δ_2, D, h_c, and k_{eff} may be obtained from Gebremedhin and Wu [2].

The above mathematical model is used to generate sufficient data of skin temperature for different values of wetness level, air velocity, relative humidity, and ambient air temperature. The same is then repeated for evaporative and convective heat losses as well. These results are then used as training data for artificial neural network (ANN). Before discussing the results obtained from ANN, the detailed methodology and parameters of ANN used in the present analysis are described in the following section.

Artificial Neural Network

Artificial neural networks are based on the working process of human brain in decision-making. Typical neural network consists of sets of processing units arranged in layers and connected in the desired fashion. Each connection has an associated weight and each unit has an associated bias. The activation of a unit is calculated by the sum of the product of weights and inputs to units. The output from a unit is obtained through an output function acting on the net activation. By knowing the input vector, the output can be predicted. In other words, the network is defined to correlate between the inputs and the outputs by training the network with available data. Once the network is trained, it can then be fed with any unknown input vector and is expected to predict the output with a high degree of accuracy.

The multi-layered feedforward fully-connected network trained by Levenberg-Marquardt training algorithm is used here because of its documented ability to model any function [8], [9]. A multi-layered neural network is made up of an input layer, at the lowest level, consisting of a unit for each element of the input vector, an output layer consisting of a unit for each element of the output vector, and one or more hidden layers placed between the input layer and the output layer. In a fully connected network, each unit of the lower layer is connected to each unit of the next layer. The network is feed-forward in the sense that information flows in only one direction, from lower layer to higher layers. The error is however propagated in the reverse direction during training process. The number of nodes (called neurons) in the hidden layer(s) is a critical parameter that is to be arrived at judiciously for optimum performance. The training of the network is expected to result in an optimum network topology and weights and biases.

Although a single network could theoretically predict all the three output variables, it seemed wiser to train a separate network for each output variable after considerable thought and exercise. A separate network for each output variable was trained because the network was simple and the training required relatively less computational time. The training data set consisted of 2000 points in the four dimensional space chosen randomly according to uniform probability distribution. The test data set was separately obtained through the same probability distribution i.e. uniform probability distribution. The training data were presented to the network in a random fashion. The input layer consisted of four neurons corresponding to the four input variables namely wetness percent (β), air velocity (V_o), relative humidity (*RH*), and ambient air temperature, (T_a) and the output layer consisted of a single neuron corresponding to the output variable namely either the skin surface temperature (T_{skin}), or the evaporative heat loss (Q_{evap}), or the convective heat loss (Q_{conv}). As mentioned earlier, the network has four input variables. The values of these input variables were generated randomly in the given range using a computer program made in FORTRAN 77 exclusively for this purpose and subsequently the values of input variables were used in the same computer program to predict the value of output variables. The final network topology and training functions are shown in Table 1; where for example the network architecture for training and prediction of all output variables contain 10, 10, 10 and 1 neurons in the first hidden layer, second hidden layer, third hidden layer and the output layer respectively. It should be noted here that a large number of different network architecture for training and prediction of all output variables was used and the performance of each network was measured in terms of maximum absolute error as well as mean squared error (MSE). After a large number of trials, it was found that the network architecture 10, 10, 10, 1 gave satisfactory values of both performance measures and therefore, this architecture was selected for training and prediction. Figure 2 shows the architecture of the network used for training and prediction of the output variables. Levenberg-Marquardt training algorithm was used in all trainings and the tanh transfer function (output function of units) on all units of hidden layers was found to provide the best results. The output function at the single unit of output layer was pure linear. To improve the performance of Levenberg-Marquardt algorithm, the inputs and outputs were normalized to a scale of – 1 to 1 for each training vector.

Table 1: The ANN model parameters

ANN model	
Neuron scheme	4 – 10 – 10 – 10 - 1
Training algorithm	Levenberg-Marquardt
Transfer function	tanh
Initial μ	0.001
μ_{dec}	0.1
μ_{inc}	10
$\mu_{\max}$	1.0e + 10

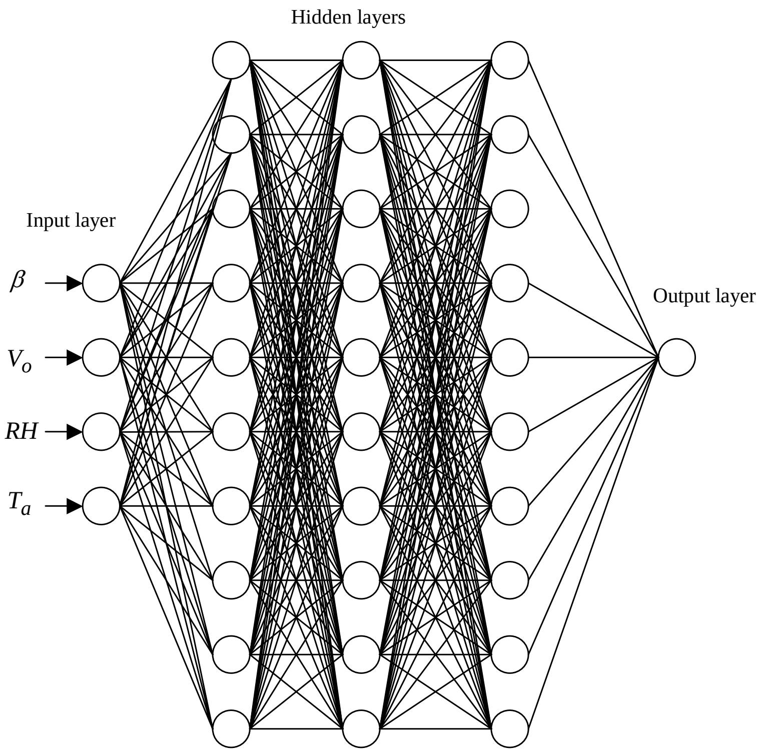

Figure 2: Architecture of the Multilayered Neural Network (ANN)

The Levenberg-Marquardt algorithm, like quasi Newton methods, uses the following update scheme:

$$X_{k+1} = X_k - \left[J^T J + \mu I\right]^{-1} J^T e$$

Where, J is the Jacobian matrix that contains first derivatives of the network errors with respect to the weights and biases, and e is a vector of network errors. The approximation to Hessian matrix is obtained by $J^T J$ and μ is a scalar. The scalar μ is decreased by multiplying by μ_{dec} after each successful step (reduction in performance function, which has the form of a sum of squares). It is increased by multiplying it by μ_{inc} whenever a step would increase the performance function. This ensures that the algorithm shifts to Newton's method as quickly as possible, resulting in faster and accurate convergence in the neighbourhood of an error minimum. If μ becomes larger than a value $\mu_{\max}$, the algorithm is stopped. The initial value of μ, and the multiplying factors μ_{dec}, μ_{inc}, and terminating value $\mu_{\max}$ are also given in Table 1. A test set containing 2000 data points was used to test the performance of the trained ANN in each case. Table 2 gives the errors obtained for the test set in case of all the three output variables. It should be emphasized that many other topologies, training/learning algorithms, and the logical sigmoid function were also tried before arriving at the final topology and training parameters.

Table 2: Performance of Network Models with Test Data

Output Variable	Maximum Absolute Error	Mean Squared Error (MSE)
Skin temperature (T_{skin})	0.24 °C	1.9e-004 °C
Evaporative heat loss (Q_{evap})	14.24 (W)	1.21 (W)
Convective heat loss (Q_{conv})	6.44 (W)	0.37 (W)

It is worth while to mention here that multiple linear regression (MLR) and power equation were also tried to fit the curve and predict the parameters, T_{skin}, Q_{evap}, and Q_{conv} respectively but no satisfactory correlations were found and, therefore, it is not being reported in this paper.

Results and Comparison

All tables and figures show the results generated from the mathematical model proposed by Gebremedhin and Wu [2] as well as artificial neural network (ANN). The mathematical model of Gebremedhin and Wu [2] is used to recalculate the values of convective heat transfer coefficient, h_c, skin temperature, T_{skin}, evaporative heat losses, Q_{evap}, and convective heat losses, Q_{conv} for different environmental and skin wetness conditions and henceforth the recalculated values are referred to as "present" value.

Table 3 shows the comparison between these present values as a function of air velocity and level of wetness, β and those given by Gebremedhin and Wu [2], as well as those obtained by ANN. These predictions are at 30°C, ambient temperature, 20% relative humidity, 26 hairs/mm^2, hair density, 3 mm pelt thickness or hair length, and 38.7°C internal body temperature similar to those taken by Gebremedhin and Wu [2]. It can be seen from Table 3 that the values of h_c obtained by Gebremedhin and Wu [2] varies with the variation in wetness in addition to the air velocity although, it should vary with the air velocity only for a fixed diameter of the cow. This fact has been used in the present analysis and revised values of h_c, T_{skin}, Q_{evap}, Q_{conv}, and have been obtained as shown in Table 3. It can be seen from this table that the revised values of the parameters are closed to those reported by Gebremedhin and Wu [2]. It may be mentioned that correspondence with Gebremedhin has confirmed that the revised values of the parameters are consistent with the theory given in their paper. ANN is then used as discussed in section 3 and their predicted results are also shown in Table 3. It can be seen from this table that the values of T_{skin}, Q_{evap}, Q_{conv}, and predicted by ANN are very close to those obtained from the mathematical model (present values) as % errors between present values and that of ANN are very small (almost negligible).

Figure 3 shows the variation in evaporative and convective heat losses with variation in the air velocity and the level of wetness (different from those shown in Table 3). It can be seen from Figure 3 that evaporative heat loss increased with increase in wetness and further enhanced with increase in air velocity. However, this trend is not observed for convective heat loss. The reason for this behaviour is attributed to the fact that even though an increased in air velocity reduced skin temperature because of faster convective cooling (consequently reducing the temperature difference (ΔT)), h_c is increased at the same time. The convective heat loss increases if the rate of increase of h_c exceeds the rate of decrease of ΔT. The decrease in convective heat loss is obtained in the reverse condition. Figure 3 also shows that the values of evaporative and convective heat losses predicted by ANN follow the same trend as that of model results and are very close to each other (almost same).

Figure 4 shows the relationship between skin temperature, T_{skin} versus air velocity and level of wetness. It can be seen from this figure that as the level of wetness increases the skin temperature drops and the drop in the skin temperature gets further enhanced with increase in the air velocity as expected. It is also evident from Figure 4 that there is almost no difference between the present and ANN values of skin temperature.

Table 3: Skin Temperature, Evaporative and Convective Heat Losses Variation as a Function of Air Velocity and Level of Wetness

Wetness (β) (%)	Air velocity (m/s)	Convective heat losses coefficient (h_c) (W/m²K)		Skin temperature (T_{skin}) (°C)				Evaporative heat losses (Q_{evap}) (W)				Convective heat losses (Q_{conv}) (W)			
		Gebre-medhin and Wu (2001)	Present value	Gebre-medhin and Wu (2001)	Present value	ANN	% error	Gebre-medhin and Wu (2001)	Present value	ANN	% error	Gebre-medhin and Wu (2001)	Present value	ANN	% error
	0.5	2.36	3.63	35.93	35.90	35.90	0.00	193.90	196.76	196.88	-0.06	61.66	61.21	61.06	0.25
25	1.0	4.16	5.50	34.86	34.83	34.82	0.03	275.87	279.63	279.52	0.04	78.34	77.52	77.54	-0.03
	2.0	8.17	8.34	33.5	33.50	33.50	0.00	392.32	390.89	390.72	0.04	87.28	88.20	87.88	0.36
	0.5	2.22	3.63	34.27	34.33	34.33	0.00	364.53	358.02	357.78	0.07	44.12	44.90	44.99	-0.20
50	1.0	4.26	5.50	32.91	32.84	32.84	0.00	486.18	494.86	495.04	-0.04	47.8	45.86	45.74	0.26
	2.0	9.93	8.34	31.32	31.11	31.11	0.00	643.85	671.83	671.14	0.10	36.56	27.95	28.03	-0.29
	0.5	2.31	3.63	32.81	33.00	32.99	0.03	513.7	494.63	494.11	0.11	28.86	31.08	31.18	-0.32
75	1.0	4.16	5.50	31.09	31.22	31.22	0.00	683.61	669.74	669.89	-0.02	17.56	19.64	19.61	0.15
	2.0	8.73	8.34	29.12	29.24	29.25	-0.03	906.33	890.78	889.96	0.09	-22.78	-19.04	-18.48	2.94

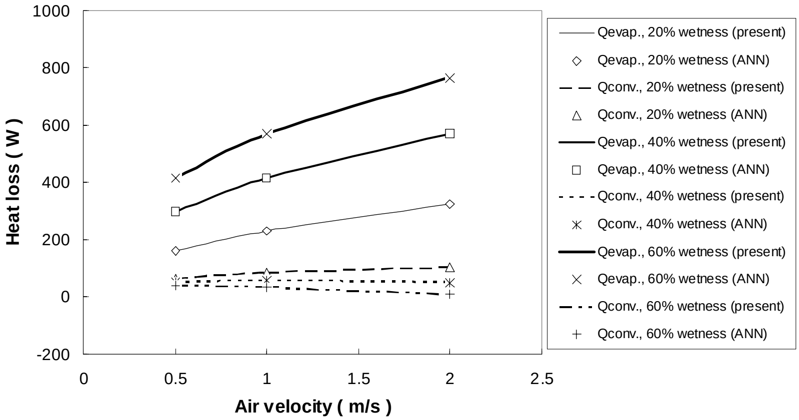

Figure 3: Evaporative and Convective Heat Losses as a Function of Air Velocity and Level of Wetness Obtained from Mathematical Model (Present) and ANN (Fixed Parameters are: 30°C Ambient Temperature, 20% Relative Humidity, 26 hairs/mm² hair Density, 3 mm hair length and 38.7°CInternal Body Temperature)

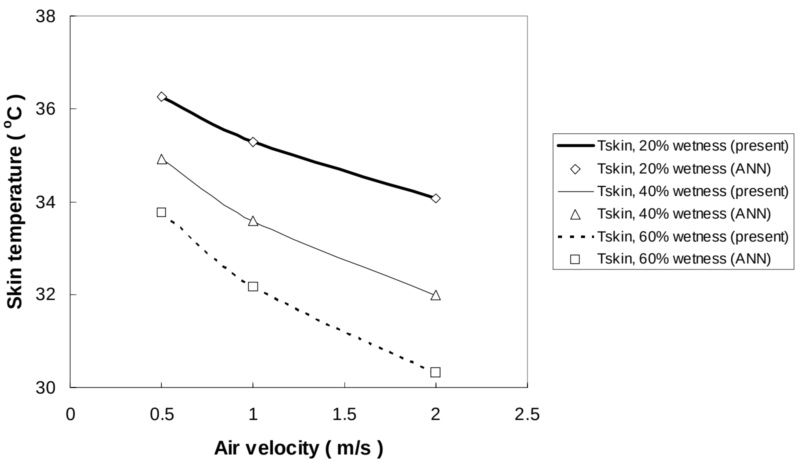

Figure 4: Skin Temperature as a Function of Air Velocity and Level of Wetness Obtained from Mathematical Model (Present) and ANN

Table 4 shows the comparison between the values of convective heat transfer coefficient, h_c, skin temperature, T_{skin}, evaporative heat losses, Q_{evap}, and convective heat losses, Q_{conv} as a function of relative humidity and level of wetness, β. These predictions are at 30°C, ambient temperature, 2 m/s air velocity, 26 hairs/mm^2, hair density, 3 mm pelt thickness or hair length, and 38.7°C internal body temperature similar to those taken by Gebremedhin and Wu [2]. Once again difference in the value h_c of and consequently small differences in the values of other parameters can be seen from Table 4. However, there is almost negligible difference between the present values of the parameters and those values predicted by ANN. From the results given in Table 4, it can be observed that as relative humidity increases, evaporative heat loss decreases but the convective heat loss increases as expected. It happens because an increase in relative humidity causes concentration deficit of water vapour between the skin surface and the ambient air which consequently suppresses the evaporative cooling. As evaporative cooling is suppressed, the temperature difference between skin and ambient air increases which results in an increased convective heat loss.

Figure 5 shows the relationship between evaporative and convective heat losses as a function of relative humidity and level of wetness (different from those given in Table 4). It is also evident from Figure 5 that ANN predicts almost same values of evaporative and convective heat losses as those obtained from the mathematical model.

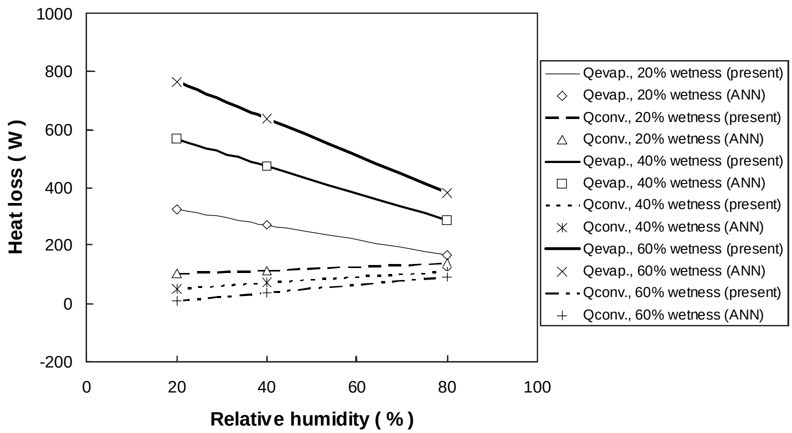

Figure 5: Evaporative and Convective Heat Losses as a Function of Relative Humidity and Level of Wetness Obtained from Mathematical Model (Present) and ANN (Fixed Parameters are: 30°C Ambient Temperature, 20% Relative Humidity, 26 hairs/mm^2 hair Density, 3 mm hair Length and 38.7°C Internal Body Temperature)

Table 4: Skin Temperature, Evaporative and Convective Heat Losses Variation as a Function of Relative Humidity and Level of Wetness

Wetness (β) (%)	Relative humidity (%)	Convective heat losses coefficient (h_c) (W/m²K)		Skin temperature (T_{skin}) (°C)				Evaporative heat losses (Q_{evap}) (W)				Convective heat losses (Q_{conv}) (W)			
		Gebre-medhin and Wu (2001)	Present value	Gebre-medhin and Wu (2001)	Present value	ANN	% error	Gebre-medhin and Wu (2001)	Present value	ANN	% error	Gebre-medhin and Wu (2001)	Present value	ANN	% error
	20	8.17	8.34	33.50	33.50	33.50	0.00	392.32	390.89	390.72	0.04	87.28	88.20	87.88	0.36
25	40	8.10	8.34	33.96	34.05	34.05	0.00	338.86	326.55	326.94	-0.12	98.20	102.03	101.94	0.09
	80	8.20	8.34	35.05	35.14	35.13	0.03	210.23	198.84	199.33	-0.25	126.10	129.41	129.65	-0.19
	20	9.93	8.34	31.32	31.11	31.11	0.00	643.85	671.83	671.14	0.10	36.57	27.95	28.03	-0.29
50	40	7.40	8.34	31.94	32.07	32.07	0.00	577.18	558.82	558.98	-0.03	45.69	52.19	52.23	-0.08
	80	7.79	8.34	33.75	33.96	33.96	0.00	365.70	337.38	337.35	0.009	90.97	99.69	99.74	-0.05
	20	8.73	8.34	29.12	29.24	29.25	-0.03	906.33	890.78	889.96	0.09	-22.78	-19.04	-18.48	2.94
75	40	8.88	8.34	30.63	30.55	30.55	0.00	727.21	737.50	737.42	0.01	16.48	13.85	14.07	-1.59
	80	7.38	8.34	32.87	33.07	33.07	0.00	469.61	441.23	441.21	0.005	67.46	77.43	77.20	0.30

Table 5 presents comparison between the values of convective heat transfer coefficient, h_c, skin temperature, T_{skin}, evaporative heat losses, Q_{evap}, and convective heat losses, Q_{conv} as a function of ambient air temperature and level of wetness, β. These predictions are at 20%, relative humidity, 2 m/s air velocity, 26 hairs/mm^2, hair density, 3 mm pelt thickness or hair length, and 38.7°C internal body temperature similar to those taken by Gebremedhin and Wu (2001). Also, in this case, the difference in the value of has been found and has resulted in different values of Q_{evap} and Q_{conv}. It can be seen from Table 5 as well as Figure 6 that for a given wetness level, ambient air temperature does not have significant effect on evaporative heat loss. This is due to the fact that at high ambient temperatures, the latent heat of vapourisation changes very little since the change in skin temperature is small. It is also evident from Table 5 that as the ambient air temperature increases, the convective heat loss decreases. The negative convective heat loss values shown in Table 5 are obtained since the ambient air temperatures are higher than respective skin temperatures. Thus, in this case, the heat transfer will take place in reverse direction i.e. from ambient air to the cow and consequently the cow will gain instead of loosing heat. From Table 5 and Figure 6, it can further be observed that ANN has predicted almost same values of the parameters since differences (%errors) between the present values and those predicted by ANN are almost negligible.

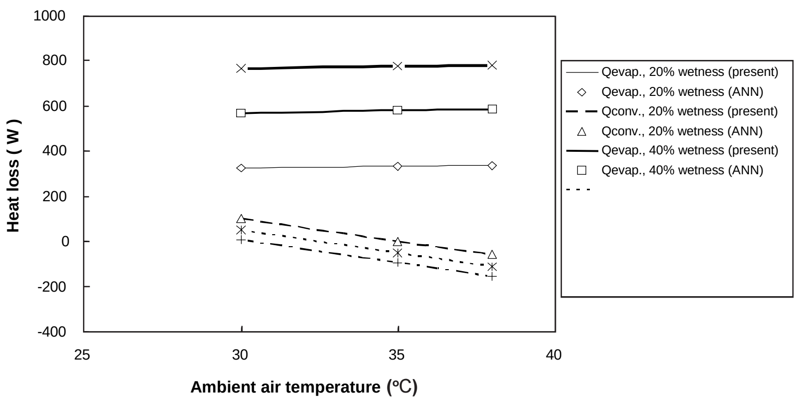

Figure 6: Evaporative and convective heat losses as a function of ambient air temperature and level of wetness obtained from mathematical model (present) and ANN (fixed parameters are: 30°C ambient temperature, 20% relative humidity, 26 hairs/mm^2 hair density, 3 mm hair length and 38.7°C internal body temperature)

Table 5: Skin Temperature, Evaporative and Convective Heat Losses Variation as a Function of Ambient Air Temperature and Level of Wetness

Wetness (β) (%)	Ambient air temperature (°C)	Convective heat losses coefficient (h_c) (W/m²K)		Skin temperature (T_{skin}) (°C)				Evaporative heat losses (Q_{evap}) (W)				Convective heat losses (Q_{conv}) (W)			
		Gebre-medhin and Wu (2001)	Present value	Gebre-medhin and Wu (2001)	Present value	ANN	% error	Gebre-medhin and Wu (2001)	Present value	ANN	% error	Gebre-medhin and Wu (2001)	Present value	ANN	% error
	30	8.17	8.34	33.50	33.50	33.50	0.00	392.32	390.89	390.72	0.04	87.28	88.20	87.88	0.36
25	35	10.14	8.34	34.53	34.49	34.49	0.00	397.32	401.26	401.15	0.03	-13.18	-12.90	-13.19	-2.25
	38	8.68	8.34	35.07	35.09	35.10	-0.03	409.71	405.65	405.73	-0.02	-75.50	-72.99	-73.17	-0.25
	30	9.93	8.34	31.32	31.11	31.11	0.00	643.85	671.83	671.14	0.10	36.57	27.95	28.03	-0.29
50	35	8.45	8.34	31.99	32.08	32.08	0.00	695.29	684.02	683.83	0.03	-76.46	-73.46	-73.50	-0.05
	38	8.31	8.34	32.93	32.69	32.69	0.00	659.17	687.97	687.97	0.00	-127.60	-133.41	-133.53	-0.09
	30	8.73	8.34	29.12	29.24	29.25	-0.03	906.33	890.78	889.96	0.09	-22.78	-19.04	-18.48	2.94
75	35	8.41	8.34	30.22	30.22	30.23	-0.03	902.54	901.57	901.57	0.00	-121.08	-120.06	-119.68	0.32
	38	8.77	8.34	30.77	30.85	30.85	0.00	918.72	903.36	903.56	-0.02	-187.44	-179.49	-179.35	0.08

Conclusions

The mathematical model of evaporative cooling of wet skin surface and fur layer proposed by Gebremedhin and Wu [2] has been used in the present analysis. From the results reported by them it appears that convective heat transfer coefficient is also a function of wetness level in addition to the air velocity for a fixed diameter of the cow. However, in the theoretical formulation of the model it is stated to be a function of diameter of the cow and air velocity only. This fact has been used in the present analysis and revised values of convective heat transfer coefficient and consequently skin temperature, evaporative as well as convective heat losses for different environmental and wetness conditions have been obtained and reported in this paper.

The revised values of the parameters have been used to train the artificial neural network in order to get predictions of these parameters for any given input variables. A multi-layered feedforward fully-connected network trained by Levenberg-Marquardt algorithm is used for this purpose. The training data set consisted of 2000 points in the four dimensional space (due to four input variables) has been chosen randomly according to uniform probability distribution. The test data set was separately obtained through the same probability distribution. The training data were presented to the network in a random fashion. Levenberg-Marquardt training algorithm was used in all trainings and the tanh transfer function (output function of units) on all units of hidden layers was found to provide the best results. The output function at the single unit of output layer was pure linear. It has been found that for different environmental and wetness conditions, the values of skin temperature, evaporative and convective heat losses predicted by ANN are very close to those obtained by the mathematical model used in the analysis.

It is mentioned here that since the neural network has already been trained, any interested person can obtain the training results in terms of weights and biases from the corresponding author.

Acknowledgements

The authors would like to thank Univesiti Sains Malaysia for providing the financial support for this research.

References

[1] Kadzere, C.T., Murphy, M.R., Silanikove, N., & Maltz, E. (2002). "Heat stress in lactating dairy cows: a review". Livestock Production Science 77, 59-91.

[2] Gebremedhin, K.G. & Wu, B. (2001). "A model of evaporative cooling of wet skin surface and fur layer". Journal of Thermal Biology 26, 537-545.

[3] Stowell, R.R. (2000). "Heat stress relief and supplemental cooling, Dairy Housing and Equipment Systems Conference Proceedings". Publ. No. 129 of the Natural Resource, Agriculture, and Engineering Service (NRAES). Agricultural and Biological Engineering Department, Cornell University, Ithaca, NY.

[4] Garner, J.C., Bucklin, R.A., Eunkle, W.E., & Nordstedt, R.A. (1989). "Sprinkled water and fans to reduce heat stress of beef cattle". Appl. Eng. Agric. 5, 99-101.

[5] Hillman, P.E., Gebremedhin, K.G. (1999). "A portable calorimeter to measure heat transfer in livestock". ASAE Paper No. 994212, ASAE, St. Joseph, MI.

[6] Chastain, J.P., & Turner, L.W. (1994). "Practical results of a model of direct evaporative cooling of dairy cows". In: Bucklin, R. (Ed.), Dairy system for the 21st Century, Proceedings of the third International Dairy Housing Conference. ASAE, St. Joseph, MI, pp. 337-352.

[7] Eksioglu, M., Fernandez, J.E., & Twomey, J.M. (1996). "Predicting peak pinch strength: Artificial neural networks vs. regression". Int. J. of Industrial Ergonomics 18, 431-441.

[8] Funahashi, K. (1989). "On the Approximate Realisation of Continuous Mappings by Neural Networks". Neural Networks 2, 183-192.

[9] Hornik, K., Stinchcombe, M., & White, H. (1989). "Multilayer feedforward networks are universal approximators". Neural Networks 2, 359-366.

ZAHID A. KHAN, G.A. QUADIR, ARIF SUHAIL & K.N. SEETHARAMU, School of Mechanical Engineering, University Sains Malaysia, 14300 Nibong Tebal, Penang, Malaysia