APPLICATION OF ARTIFICIAL NEURAL NETWORK (ANN) FOR PREDICTION OF SENSIBLE AND LATENT HEAT LOSSES FROM A COW

Zahid A. Khan
S. Kamaruddin[1]
G.A. Quadir
A. Suhail
K.N. Seetharamu

School of Mechanical Engineering
Universiti Sains Malaysia
14300 Nibong Tebal, Penang
MALAYSIA

ABSTRACT

Artificial Neural Network (ANN) based on feed-forward backpropagation model is used to predict sensible and latent heat losses from the wet-skin surface and fur layer of a cow. A mathematical model is used to generate training data to train the neural network. The predicted skin temperatures, latent, convective, radiative, sensible and total heat losses due to the change in the 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 losses, evaporative cooling, convective cooling, wet fur*

1.0 INTRODUCTION

A major factor which can adversely affect milk production of dairy cows is the thermal environment [1]. Significant reduction in the milk production and breeding efficiencies of cows due to severe heat stress caused by hot and humid environments has been reported [2]. In the absence of supplemental cooling, drops in milk yield of 20-30% following hot, muggy stretches are observed in high-producing herds [3]. In order to increase milk yield of the cows it is necessary to cool them off. A common method to cool them is to wet their hair coat and skin surface by sprinkling water on them [4]. Many other studies [3,5,6] have also reported that in hot and dry environments, animals can effectively be cooled by applying water onto their hair coat and skin surface. Using water alone to cool them however is not as effective as spraying water and blowing air simultaneously

[1] Author to whom all correspondence should be addressed; Fax: 604-5941025;
E-mail: meshah@eng.usm.my

[7]. The combined effect of wetting and blowing air results in substantial reduction in the body temperature of cows [8-12]. Sprinkling water onto cows ensures that a large wetted surface area is available for evaporation, thereby sweating activity is greatly supplemented and possibly reduced or eliminated. 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 [12]. Gebremedhin and Wu [2] have suggested that heat stress of the cow can effectively be reduced through evaporative cooling by wetting the skin and fur layer followed by blowing air over it. The heat conducted through the skin is taken up by the surface moisture as it evaporates from the wet skin surface and fur layer. This process cools the skin and consequently allows it to take more body heat. The speed with which water vapour moves through the hair coat depends on the velocity of the blowing air. 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. As moist air is removed from the fur layer and taken up by air surrounding the cow, more moist air moves through the hair coat. 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 [13] took into account this process of cooling of cows and developed a mathematical model using fluid flow and heat and mass transfer equations. In order to use the model one needs to develop a computer code since determination of parameters like skin surface temperature, evaporative, convective, radiative, sensible, and total heat losses are based on the iterative process. The objective of this paper is to present a methodology to predict these parameters for different environmental and skin wetness condition using Artificial Neural Network (ANN). The mathematical model of Gebremedhin and Wu [13] is used in the present analysis with the same assumptions and values of fixed parameters like weight and diameter of the cow, fur depth, 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.

2.0 ANALYSIS

Gebremedhin and Wu [13] 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 the sum of the thickness of fur layer (δ_1) and a thin film of air layer (δ_2) above it. The model is developed to determine skin temperatures, evaporative, convective, radiative, sensible, and total heat losses under the following assumptions:

(1) Animal geometry is represented by a cylinder.
(2) Flow, heat and mass is assumed to be steady state.
(3) Thermal properties of fur layer and air 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) The skin surface is considered to be a black body.
(8) Indoor wall temperatures are assumed to be equal to the ambient air temperature.

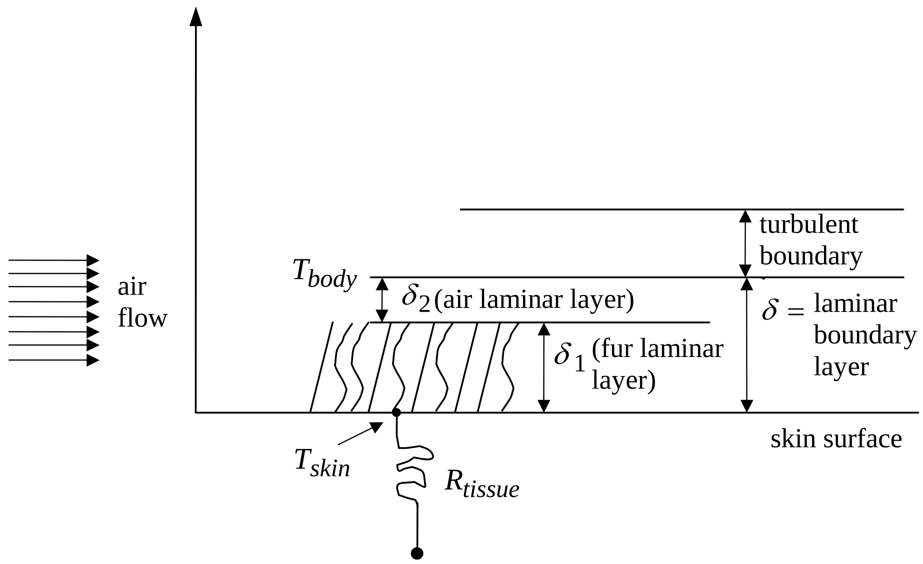

Figure 1: Schematic diagram showing laminar and turbulent boundary layers within the fur layer

The full details of their mathematical model can be found in their paper [13]. However, some related expressions are reproduced here for the purpose of completeness.

The sensible heat loss ($Q_{sensible}$) from the animal is calculated as:

$$Q_{sensible} = Q_{conv} + Q_{rad} \tag{1}$$

where, Q_{conv} is the convective heat loss from the skin surface of the animal (kJ/s),

Q_{rad} is the radiative heat loss (kJ/s).

The total heat loss (Q_{total}) from the animal to the ambient air is calculated as:

$$Q_{total} = Q_{evap} + Q_{conv} + Q_{rad} \tag{2}$$

where, Q_{evap} is the evaporative heat loss from the skin surface of the animal (kJ/s), Evaporative heat loss from the skin surface (Q_{evap}) is calculated as:

$$Q_{evap} = \lambda\, j \beta A_s \tag{3}$$

where, λ is the latent heat of vapourisation of water at the skin-surface temperature (kJ/kg water),

j is the total mass flux of water vapour (k mol/m^2 s),

β is the percent wet area of the skin surface (%), and

A_s is the surface area of the animal (m^2) which can be calculated from weight of the animal (W) as 0.15 $W^{0.56}$.

The total mass flux of water vapour (j) that evaporates from the skin surface is calculated as:

$$j = (C_{skin} - C_o) \Big/ \left(\frac{1}{h_m} + \frac{\delta_1 + \delta_2}{D} \right) \tag{4}$$

where, C_{skin} is the concentration of water vapour on the skin surface (k mol/m^3),

C_o is the concentration of water vapour in the ambient air (k mol/m^3),

h_m is the convective mass transfer coefficient (m/s),

δ_1 is the thickness of hair coat (m),

δ_2 is the thickness of air layer beyond the thickness of the hair coat (m), and D is the mass diffusive coefficient of water vapour (m^2/s).

The convective heat loss from the skin surface (Q_{conv}) is calculated as:

$$Q_{conv} = (T_{skin} - T_a) A_s \Big/ \left(\frac{1}{h_c} + \frac{\delta_1}{k_{eff}} + \frac{\delta_2}{k_{air}} \right) \tag{5}$$

where, T_{skin} is the skin surface temperature (K or ^{o}C),

T_a is the ambient air temperature (K or ^{o}C),

h_c is the convective heat transfer coefficient (W/m^2 K),

k_{eff} is the mean effective thermal conductivity of the fur layer (W/m K), and k_{air} is the thermal conductivity of the ambient air (W/m K).

The radiative heat loss (Q_{rad}) is calculated as:

$$Q_{rad} = \varepsilon\ f_{fur}\ f_{eff}\ h_r\ A_s\ (T_{skin} - T_{mrt}) \tag{6}$$

where, ε is the radiant emissive coefficient of animal skin (non-dimensional),

f_{fur} is the ratio of fur surface area to skin surface area (%),

f_{eff} is the coefficient of effective radiant area (non-dimensional),

h_r is the coefficient of radiant heat transfer (W/m^2 K), and

T_{mrt} is the mean radiant temperature, assumed to be equal to the ambient temperature (K or ^oC).

The skin temperature is influenced by both heat and mass transfer, and thus are coupled. The skin temperature is calculated from:

$$Q_{total} = A_s(T_{body} - T_{skin})/R_{tissue} \tag{7}$$

where, T_{body} is the average internal body temperature (K or ^oC), and

R_{tissue} is the heat resistance of tissue (m^2 K/W).

Combining equations (3) and (5) through (7), the evaporative heat loss (Q_{evap}), convective heat loss (Q_{conv}), radiative heat loss (Q_{rad}) and skin temperature (T_{skin}) are solved by iteration. Other details including details of evaluating C_{skin}, C_o, h_m, δ_2, D, h_c, and k_{eff} may be obtained from Gebremedhin and Wu [13].

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, convective, radiative, sensible, and total heat losses as well. These results are then used as training data for 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.

3.0 ARTIFICIAL NEURAL NETWORK (ANN)

Artificial neural networks are based on the working process of human brain in decision making. ANN have been successfully applied to a variety of function approximation or classification problems e.g. quality inspection, weather forecasting, speech/image understanding, automatic control and robot system, character recognition, sonar classification, etc. [14]. 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 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 backpropagation is used here because of its documented ability to model any function [15,16]. 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 layer(s) 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. Units in each layer receive signals from the previous layer and the signal emanating from a unit is obtained through an output function acting on the summation of outer products of input signals and connection weights. 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 a network involves presenting the training data set and minimizing the error between correct outputs in the data set and network outputs through some learning/training algorithm. The result of such training is an optimum network topology and the resulting weights and biases.

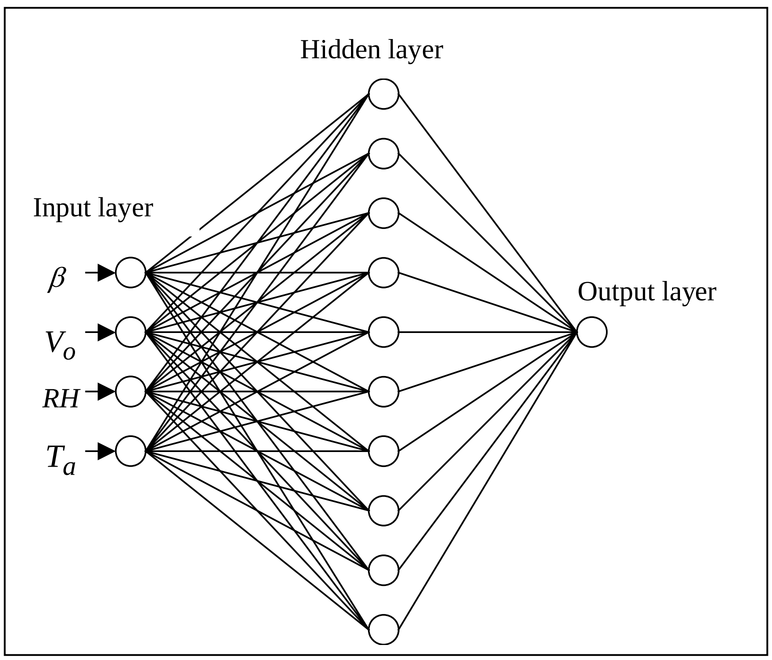

Figure 2: Architecture of the multilayered ANN for all the output variables except convective heat loss

Although a single network could theoretically predict all the six output variables, it seemed wiser to train a separate network for each output variable after considerable thought and exercise. The training data set consisted of 1000 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. 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}), or the radiative heat loss (Q_{rad}), or the sensible heat loss $(Q_{sensible})$, or the total heat loss (Q_{total}). 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 except convective heat loss (Q_{conv}) contains 10 and 1 neurons in the hidden layer and the output layer respectively. Figure 2 shows the architecture of the network used for training and prediction of the all output variables except Q_{conv}. Levenberg-Marquardt training algorithm was used in all trainings and the tanh transfer function (output function of units) on all units of hidden layer 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.

The Levenberg-Marquardt algorithm, like quasi Newton's method, uses the following update scheme:

$$X_{k+1} = X_k - \left[J^T J + \mu I\right]^{-1} J^T e \tag{8}$$

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 μ_{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 1000 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 six 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 1: The ANN model parameters

ANN model	T_{skin}, Q_{evap}, Q_{rad}, $Q_{sensible}$, Q_{total}	Q_{conv}
Neuron scheme	4 – 10 – 1	4 – 15 – 1
Training algorithm	Levenberg-Marquardt	Levenberg-Marquardt
Transfer function	tanh	tanh
Initial μ	0.001	0.001
μ_{dec}	0.1	0.1
μ_{inc}	10	10
$\mu_{\max}$	1.0e+10	1.0e+10

Table 2: Performance of network models with test data

Output Variable	Maximum Absolute Error	Mean Squared Error (MSE)
Skin temperature (T_{skin})	0.08 ^{o}C	4.13e-004 ^{o}C
Evaporative heat loss (Q_{evap})	9.87 (W)	7.04 (W)
Convective heat loss (Q_{conv})	1.52 (W)	0.17 (W)
Raditive heat loss (Q_{rad})	1.51 (W)	0.18 (W)
Sensible heat loss $(Q_{sensible})$	2.53 (W)	0.66 (W)
Total heat loss (Q_{total})	6.08 (W)	3.41 (W)

It is worthwhile 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}, Q_{conv}, Q_{rad}, $Q_{sensible}$ and Q_{total} respectively but no satisfactory correlations were found and, therefore, it is not being reported in this paper.

4.0 RESULTS AND COMPARISON

It appears from the results of Gebremedhin and Wu [2] that the value of the convective heat transfer coefficient, h_c 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 a cow. Correspondence with Gebremedhin confirmed the above fact with regard to h_c. The mathematical model of Gebremedhin and Wu [13] is used to recalculate the values of h_c, first. The same model is then used to determine skin temperature, T_{skin}, evaporative heat loss, Q_{evap}, convective heat loss, Q_{conv} and radiative heat loss, Q_{rad} for different environmental and skin wetness conditions. These recalculated values are referred to as “present” values. Table 3 shows the present generated results as a function of air velocity and level of wetness β along with the results given by Gebremedhin and Wu [13]. ANN, as discussed in section 3, is then used and its predicted results are also shown in Table 3. All the results are obtained for constant values of ambient air temperature of 30^{o}C and relative humidity of 20% while keeping the following parameters constant: hair density as 26 hairs/mm^2, fur depth of 3 mm and internal body temperature as 38.7^{o}C, similar to those taken by Gebremedhin and Wu [13]. It may be mentioned that the above constant parameters are valid for all other tables and figures that follow. It can be seen from Table 3 that there are differences (though small) between the present values and those given by Gebremedhin and Wu [13] mainly due to the difference in the value of h_c. However, the values of the parameters predicted by ANN are very close to the present values as evident from the percentage error (calculated on the basis of the present values) as shown in the same table against each parameter.

Figure 3 shows the variation in evaporative/latent, convective, radiative, sensible and total heat losses with the variation in the level of wetness for an ambient air temperature of 30^{o}C, relative humidity of 20% and air velocity as 2 m/s. It can be seen from this figure that as the level of wetness increases, the evaporative/latent heat loss increases since more wet skin surface area is available for evaporative heat losses. Due to increased evaporative heat loss, the skin surface is cooled at a faster rate and consequently the temperature gradient between the skin surface and ambient air decreases which results in decreased convective as well as radiative heat losses. The sensible heat loss, being sum of convective and radiative heat losses also decreases with increasing level of wetness. However, the total heat loss which is sum of latent and sensible heat losses increases with increasing wetness level but its value is lower than the latent heat loss particularly at high wetness level.

Table 3: Skin temperature, latent, convective, radiative, sensible, and total heat losses variation as a function of air velocity and level of wetness

Wetness percent β (%)	Air velocity (m/s)	Identity	Skin temperature T_{skin} (^{o}C)				Latent heat loss Q_{latent} (W)				Convective heat loss Q_{conv} (W)			
			Gebremedhin and Wu (2002)	Present value	ANN	% error	Gebremedhin and Wu (2002)	Present value	ANN	% error	Gebremedhin and Wu (2002)	Present value	ANN	% error
	0.5	A	35.0	35.01	35.04	-0.09	182	186.57	181.43	2.75	52	51.98	52.44	-0.88
25	1.0	B	34.2	34.15	34.14	0.03	277	268.42	269.68	-0.47	65	66.72	66.21	0.76
	2.0	C	33.2	33.06	33.05	0.03	368	380.39	377.42	0.78	81	77.17	77.80	-0.82
	0.5	D	33.7	33.72	33.72	0.00	342	344.93	345.61	-0.20	39	38.60	38.48	0.31
50	1.0	E	32.4	32.48	32.46	0.06	487	483.76	486.47	-0.56	39	39.80	39.47	0.83
	2.0	F	30.7	30.99	30.99	0.00	690	666.45	667.72	-0.19	17	24.83	25.12	-1.17
	0.5	G	32.6	32.60	32.62	-0.06	481	482.53	477.85	0.97	27	26.99	26.60	1.44
75	1.0	H	30.8	31.08	31.07	0.03	683	663.52	663.41	0.02	13	17.33	16.74	3.40
	2.0	I	29.3	29.32	29.29	0.10	906	895.45	897.82	-0.26	-19	-17.09	-17.50	-2.40

Table 3 (continued)

Identity	Radiative heat loss Q_{rad} (W)				Sensible heat loss $Q_{sensible}$ (W)				Total heat loss Q_{total} (W)			
	Gebremedhin and Wu (2002)	Present value	ANN	% error	Gebremedhin and Wu (2002)	Present value	ANN	% error	Gebremedhin and Wu (2002)	Present value	ANN	% error
A	107	101.45	102.33	-0.87	159	153.44	154.84	-0.91	341	340.01	336.10	1.15
B	86	84.07	84.15	-0.09	151	150.78	150.24	0.36	428	419.20	420.07	-0.21
C	68	62.03	60.48	2.45	149	139.20	140.90	-1.22	517	519.59	520.68	-0.21
D	79	75.34	75.60	-0.34	118	113.95	114.37	-0.37	459	458.88	459.40	-0.11
E	52	50.15	50.11	0.08	91	89.94	89.97	-0.03	577	573.70	575.76	-0.36
F	14	19.96	19.76	1.00	31	44.79	45.74	-2.12	722	711.24	712.22	-0.14
G	55	52.67	54.25	-3.00	82	79.66	81.36	-2.13	563	562.19	557.77	0.79
H	17	21.83	21.47	1.65	30	39.16	38.94	0.56	713	702.68	704.38	-0.24
I	-16	-13.74	-14.16	-3.06	-35	-30.82	-31.80	-3.18	871	864.62	865.20	-0.07

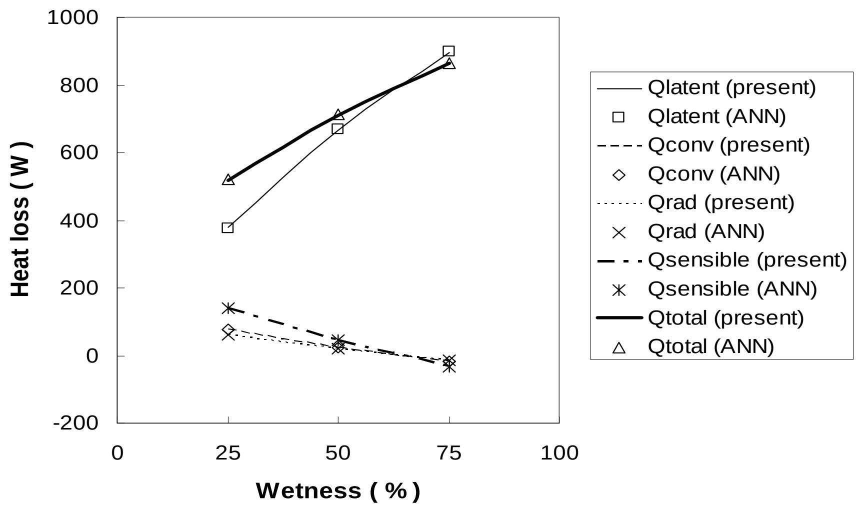

Figure 3: Latent, convective, radiative, sensible, and total heat losses as a function of percent of wetness obtained from mathematical model (present) and ANN

Figure 4 shows the effect of air velocity on evaporative/latent, convective, radiative, sensible and total heat losses. The fixed parameters for the relationships shown in this figure are: 30^{o}C ambient air temperature, 20% relative humidity, and 50% level of wetness. It can be seen from this figure that for these conditions, evaporative heat loss increases with increasing air velocity because moisture is evaporated at a faster rate due to blowing air. However, the convective as well as radiative heat losses decrease with increasing air velocity and, therefore, causes reduction in sensible heat loss. So far as total heat loss is concerned, it increases with increasing air velocity. Both Figures 3 and 4 also show that the values of evaporative/latent, convective, radiative, sensible and total heat losses predicted by ANN follow the same trend as that of model results and are very close to each other.

The combined effect of wetness level and air velocity on evaporative/latent, convective, radiative, sensible and total heat losses are shown in Table 3. It can be seen from this table that evaporative/latent heat loss increases with increasing level of wetness and is further enhanced with increasing air velocity. Enhanced evaporative cooling cools the skin surface and consequently the temperature gradient between the skin surface and ambient air decreases which results in decreased convective and radiative heat losses and thereby the sensible heat loss. It can also be seen from Table 3 that as the air velocity increases, the convective heat loss also increases but only at lower wetness level i.e. 25%. However, at higher wetness level it decreases with increasing air velocity. The radiative heat loss also decreases with increasing wetness as well as increasing air velocity and, therefore, these two losses combined together cause reduction in sensible heat loss. The negative values shown in Table 3 indicate sensible heat gain rather than heat loss. This condition is possible when the skin temperature is lower than the ambient air temperature.

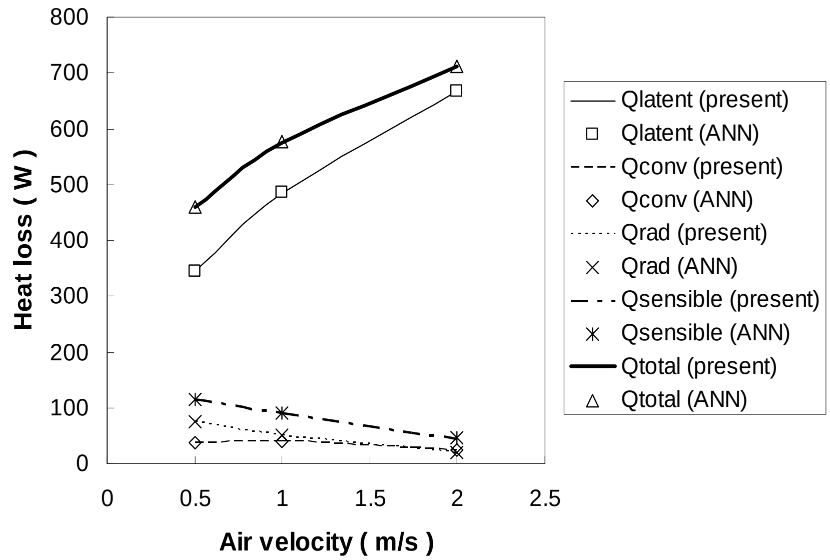

Figure 4: Latent, convective, radiative, sensible, and total heat losses as a function of air velocity obtained from mathematical model (present) and ANN

Table 4 shows the comparison between the values of the parameters as a function of relative humidity and level of wetness, β for constant values of ambient air temperature of 30^{o}C and air velocity of 2 m/s. Once again small differences between the values of the parameters obtained by Gebremedhin and Wu [13] and present values can be seen from this table. However, there is almost negligible difference between the present values of the parameters and those predicted by ANN.

Table 4: Skin temperature, latent, convective, radiative, sensible, and total heat losses variation as a function of relative humidity and level of wetness

Wetness percent β (%)	Air velocity (m/s)	Identity	Skin temperature T_{skin} (^oC)				Latent heat loss Q_{latent} (W)				Convective heat loss Q_{conv} (W)			
			Gebremedhin and Wu (2002)	Present value	ANN	% error	Gebremedhin and Wu (2002)	Present value	ANN	% error	Gebremedhin and Wu (2002)	Present value	ANN	% error
25	20	A	33.2	33.06	33.05	0.03	368	380.39	377.42	0.78	81	77.17	77.80	-0.82
	40	B	33.5	33.55	33.51	0.12	312	314.12	313.57	0.18	90	89.30	89.35	-0.05
	80	C	34.5	34.50	34.45	0.14	182	182.39	184.13	-0.95	114	113.3 9	113.5 5	-0.14
50	20	D	30.7	30.99	30.99	0.00	690	666.45	667.72	-0.19	17	24.83	25.12	-1.17
	40	E	32.0	31.84	31.84	0.00	528	548.40	550.38	-0.36	51	46.41	46.39	0.04
	80	F	33.5	33.53	33.52	0.03	313	316.25	318.09	-0.58	89	88.91	89.04	-0.15
75	20	G	29.3	29.32	29.29	0.10	906	895.45	897.82	-0.26	-19	-17.09	-17.50	2.40
	40	H	30.5	30.49	30.48	0.03	727	733.96	735.56	-0.22	13	12.46	12.09	2.97
	80	I	33.0	32.78	32.78	0.00	395	419.93	418.33	0.38	75	69.92	70.08	-0.23

Table 4 (continued)

Identity	Radiative heat loss Q_{rad} (W)				Sensible heat loss $Q_{sensible}$ (W)				Total heat loss Q_{total} (W)			
	Gebremedhin and Wu (2002)	Present value	ANN	% error	Gebremedhin and Wu (2002)	Present value	ANN	% error	Gebremedhin and Wu (2002)	Present value	ANN	% error
A	68	62.03	60.48	2.50	149	139.20	140.90	-1.22	517	519.59	520.68	-0.21
B	75	71.77	70.50	1.77	165	161.07	160.76	0.19	477	475.19	477.06	-0.39
C	96	91.14	89.45	1.85	210	204.53	204.19	0.17	393	386.92	389.14	-0.57
D	14	19.96	19.76	1.00	31	44.79	45.74	-2.12	722	711.24	712.22	-0.14
E	43	37.31	37.56	-0.67	94	83.72	83.46	0.31	622	632.12	633.53	-0.22
F	75	71.47	71.48	-0.01	164	160.38	158.93	0.90	477	476.63	478.93	-0.48
G	-16	-13.74	-14.16	-3.05	-35	-30.82	-31.80	-3.18	871	864.62	865.20	-0.07
H	11	10.01	9.98	0.30	23	22.47	22.03	1.96	751	756.42	756.34	0.01
I	63	56.20	56.51	-0.55	138	126.12	126.04	0.06	534	546.05	545.21	0.15

Figure 5 shows the effect of relative humidity on evaporative/latent, convective, radiative, sensible and total heat losses when the ambient air temperature, air velocity and level of wetness are kept constant at 30^{o}C, 2 m/s, and 50% respectively. It can be seen from this figure that as relative humidity increases, the latent heat loss decreases resulting in the reduction of total heat loss. The decrease in the latent heat loss is due to decrease in vapour concentration gradient between the skin surface and ambient air with increasing relative humidity. A decrease in evaporative cooling, results in an increase of skin surface temperature. Consequently convective and radiative heat losses increase and thereby sensible heat loss increases which is also evident from Table 4. It is also evident from Figure 5 that ANN predicts almost same values of these parameters as those obtained from the mathematical model.

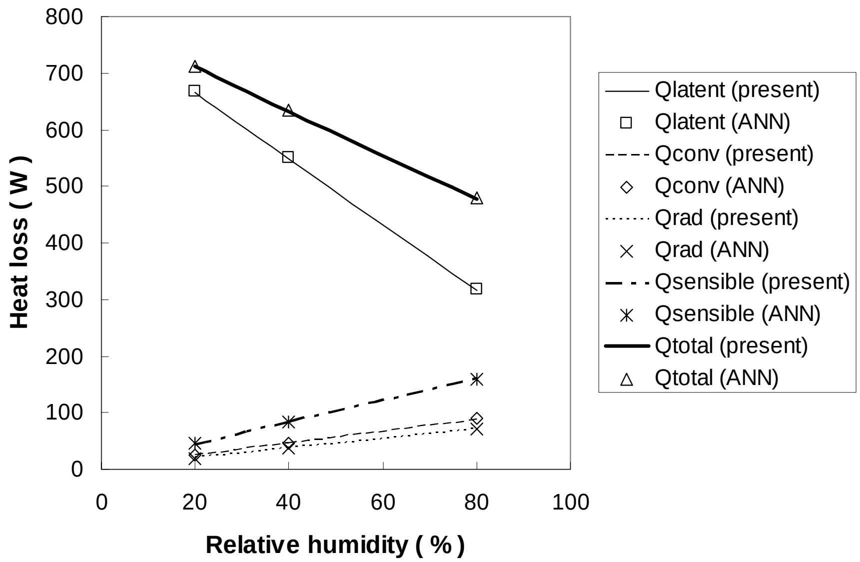

Figure 5: Latent, convective, radiative, sensible, and total heat losses as a function of relative humidity obtained from mathematical model (present) and ANN.

Table 5 presents comparison between the values of the parameters as a function of ambient air temperature and level of wetness, β for 20%, relative humidity and 2 m/s air velocity. Table 5 also shows small difference between the values of the parameters obtained by Gebremedhin and Wu [13] and present values. However, the difference between the present values of the parameters and those predicted by ANN is almost negligible.

The effect of ambient air temperature on evaporative/latent, convective, radiative, sensible, and total heat losses is shown in Figure 6. The relationships shown in this figure are for 2 m/s air velocity, 20% relative humidity and 50%

level of wetness. It is evident from this figure as well as from Table 5 that for a given wetness level, ambient air temperature does not have significant effect on latent 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 can also be seen that as the ambient air temperature increases, the convective, radiative, sensible, and total heat losses decrease. The negative sensible heat loss values shown in Table 5 are due to ambient air temperatures being higher than the 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 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.

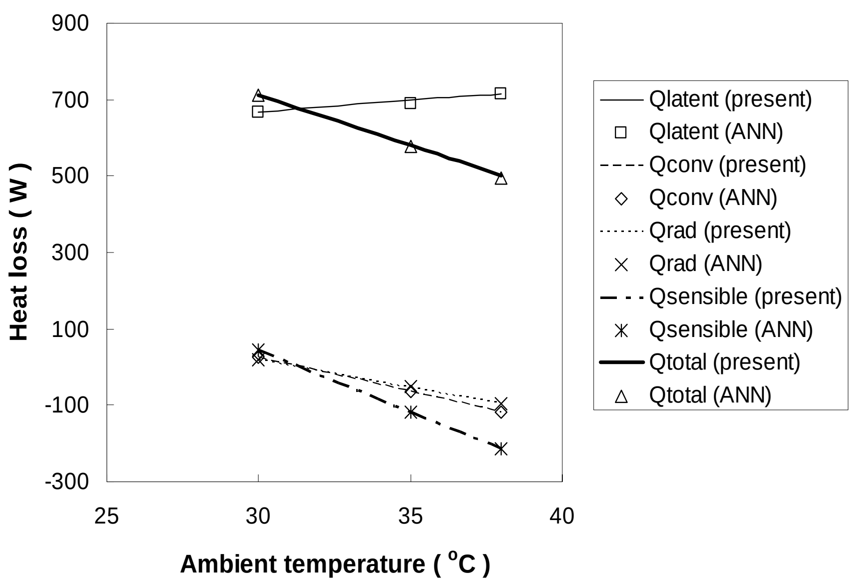

Figure 6: Latent, convective, radiative, sensible, and total heat losses as a function of ambient air temperature obtained from mathematical model (present) and ANN.

Table 5: Skin temperature, latent, convective, radiative, sensible, and total heat losses variation as a function of ambient air temperature and level of wetness

Wetness percent β (%)	Air velocity (m/s)	Identity	Skin temperature T_{skin} (^{o}C)				Latent heat loss Q_{latent} (W)				Convective heat loss Q_{conv} (W)			
			Gebremedhin and Wu (2002)	Present value	ANN	% error	Gebremedhin and Wu (2002)	Present value	ANN	% error	Gebremedhin and Wu (2002)	Present value	ANN	% error
25	30	A	33.2	33.06	33.05	0.03	368	380.39	377.42	0.78	81	77.17	77.80	-0.82
	35	B	34.6	34.55	34.51	0.12	398	402.93	397.89	1.25	-9	-11.28	-11.41	-1.15
	38	C	35.5	35.45	35.39	0.17	409	415.36	421.94	-1.58	-62	-64.02	-64.66	-1.00
50	30	D	30.7	30.99	30.99	0.00	690	666.45	667.72	-0.19	17	24.83	25.12	-1.17
	35	E	32.5	32.40	32.42	-0.06	694	699.11	690.44	1.24	-64	-65.39	-64.39	1.53
	38	F	33.3	33.26	33.29	-0.09	710	716.33	715.14	0.17	-118	-118.95	-116.81	1.80
75	30	G	29.3	29.32	29.29	0.10	906	895.45	897.82	-0.26	-19	-17.09	-17.50	2.40
	35	H	31.0	30.70	30.71	-0.03	900	932.64	926.39	0.67	-101	-108.06	-107.78	0.26
	38	I	31.9	31.55	31.62	-0.22	917	951.36	949.25	0.22	-154	-161.85	-160.66	0.74

Table 5 (continued)

Identity	Radiative heat loss Q_{rad} (W)				Sensible heat loss $Q_{sensible}$ (W)				Total heat loss Q_{total} (W)			
	Gebremedhin and Wu (2002)	Present value	ANN	% error	Gebremedhin and Wu (2002)	Present value	ANN	% error	Gebremedhin and Wu (2002)	Present value	ANN	% error
A	68	62.03	60.48	2.50	149	139.20	140.90	-1.22	517	519.59	520.68	-0.21
B	-8	-10.08	-10.03	0.49	-17	-21.36	-21.64	-1.31	381	381.57	383.85	-0.60
C	-52	-51.62	-52.15	-1.03	-115	-115.64	-117.49	-1.60	294	299.72	301.71	-0.66
D	14	19.96	19.76	1.00	31	44.79	45.74	-2.12	722	711.24	712.22	-0.14
E	-54	-52.67	-52.22	0.85	-118	-118.05	-116.97	0.91	576	581.06	577.84	0.55
F	-99	-95.92	-95.04	0.91	-216	-214.87	-212.73	1.00	494	501.46	494.30	1.43
G	-16	-13.74	-14.16	-3.05	-35	-30.82	-31.80	-3.18	871	864.62	865.20	-0.07
H	-85	-87.03	-86.24	0.91	-185	-195.09	-194.18	0.47	715	737.55	733.62	0.53
I	-130	-130.51	-128.95	1.19	-283	-292.35	-289.78	0.88	633	659.01	648.77	1.55

5.0 CONCLUSIONS

The mathematical model for determining sensible and latent heat losses from wet-skin surface and fur layer for a cow as proposed by Gebremedhin and Wu [13] has been used in the present analysis with the modified values of convective heat transfer coefficient, under different environmental and wetness conditions. The revised values of parameters (skin temperature, evaporative/latent, convective, radiative, sensible and total heat losses) have been used to train the ANN in order to get predictions of these parameters for any given input variables. The following conclusions may be drawn from the results obtained in the present analysis:

1. The sensible heat loss decreases with the increase in either level of wetness or air velocity or ambient air temperature whereas it increases with the increase in relative humidity for other fixed environmental and wetness conditions.
2. The latent heat loss increases with the increase in either level of wetness or air velocity, decreases with the increase the relative humidity whereas it increases marginally with the increase in ambient air temperature for other fixed environmental and wetness conditions.
3. It has been found that for different environmental and wetness conditions the values of skin temperature, latent, convective, radiative, sensible, and total heat losses predicted by ANN are very close to those obtained by the mathematical model used in the analysis.

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, pp. 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, pp. 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. Igono, M., O., Stevens, B. J., Shanklin, M. D., Johnson, H. D., (1985), "*Spray cooling effects on milk production, milk, rectal temperatures of cows during moderate temperature summer season*". Journal of Dairy Science, 68, pp. 979-985.

5. 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, (1), pp. 99-101.
6. Hillman, P. E., Gebremedhin, K.G., (1999), "*A portable calorimeter to measure heat transfer in livestock*". ASAE Paper No. 994212, ASAE, St. Joseph, MI.
7. Lin, J. C., Moss, B. R., Koon, J. L., Flood, C. A., Smith III, R. C., Cummins, K. A., Coleman, D. A., (1998), "*Comparison of various fan, sprinkler, and mister systems in reducing heat stress in dairy cows*". Appl. Eng. Agric. 14, (2), pp. 177-182.
8. Flamenbaum, I., Wolfenson, D., Mamen, M., Berman, A., (1986), "*Cooling dairy cattle by a combination of sprinkling and forced ventilation and its implementation in the shelter system*". Journal of Dairy Science, 69, pp. 3140-3147.
9. Igono, M., O., Johnson, H. D., Stevens, B. J., Krause, G. F., Shanklin, M. D., (1987), "*Physiological, productive, and economic benefits of shade, spray, and fan system versus shade for Holstein cows during summer heat*". Journal of Dairy Science, 70, pp. 1069-1079.
10. Kimmel, E., Arkin, H., Berman, A., (1992), "*Evaporative cooling of cattle: transport phenomena and thermo vision*". Presented at the 1992 ASAE Summer International Meeting, Paper No. 924028, ASAE, 2950 Niles Rd., St. Joseph, MI 49085-9659, USA.
11. Turner, L. W., Chastain, J. P., Hemken, R. W., Gates, R. S., Crist, W. L., (1992), "*Reducing heat stress in dairy cows through sprinkler and fan cooling*". Appl. Eng. Agric. 8, (2), pp. 251-256.
12. 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 the 21st Century, Proceedings of the third International Dairy Housing Conference. ASAE, St. Joseph, MI, pp. 337-352.
13. Gebremedhin, K. G., Wu, B., (2002), "*Simulation of sensible and latent heat losses from wet-skin surface and fur layer*". Journal of Thermal Biology, 27, pp. 291-297.
14. Eksioglu, M., Fernandez, J. E., Twomey, J. M., (1996), "*Predicting peak pinch strength: Artificial neural networks vs. regression*". International Journal of Industrial Ergonomics, 18, pp. 431-441.
15. Funahashi, K., (1989), "*On the Approximate Realisation of Continuous Mappings by Neural Networks*". Neural Networks, 2, pp. 183-192.
16. Hornik, K., Stinchcombe, M., White, H., (1989), "*Multilayer feedforward networks are universal approximators*". Neural Networks, 2, pp. 359-366.