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Heat and Vapor Production of Dairy Heifers and Sheep

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ABSTRACT. Seven experiments in total with three replicates per experiment were cnducted to determine the heat and moisture produced and efficiency of feed utilization for growing dairy heifers and sheep under actual production conditions. Total heat production for dairy heifers was linearly decreased from 278 to 152 Watt/100 kg as they grew from 98 to 305 kg. The decrease of total heat produced for sheep, on the other hand, was from 10 to 4.3 Watt/kg as they grew from 20 to 53 kg. Heat loss by evaporation represented an average of 37% and 68% of the total heat produced by heifers and sheep respectively. Linear regression equations were developed to predict the heat losses as function of animal body weight. The effect of body covering or fleece thickness on sheep heat losses were also studied. The percent of sensible heat loss to the total heat loss increased from 14% to 52% as fleece were sheared from 9 to 0.4 cm. Growth rate and feed efficiency were also determined. The feed efficiency decreased from 0.41 to 0.11 as heifers grew from 98 to 305 kg, while the drop was from 0.33 to 0.16 as sheep grew from 20 to 53 kg.

Environment is of major concern when attention is directed toward improving animal productivity and managing wildlife. The interrelationships between animals and their environment serve to answer questions in various fields (Yeck 1971). Such fields are human and animal nutrition, health, production and reproduction, behavior, preservation of rare wildlife species, management, pollution abatement, and environmental engineering. Animal performance represented by the growth rate is of greatest economic significance (Wiersma and Stott 1969). It is, as in many complex biological systems, influenced by many factors such as breed, sex, environmental conditions, and noxious gas concentration. With production as the prime concern, the rate of gain or growth, efficiency of feed utilization, and milk production have been commonly used as quantitative indices for environmental studies.

Ventilation management is one of the most important means of environmental control in livestock buildings. Good practice and improved management strategies of livestock buildings require efficient use of equipment and housing. Reliable data of animal heat and moisture production are considered the main criteria of the proper selection and sizing of ventilation and heating systems. They must be predictable so that environmental control equipment can be designed to maintain an environment conducive to optimum livestock production. In other words, the quantity of sensible heat and water vapor produced in a building can be used to design and size the auxiliary heating, cooling, and fan systems that make life for animals in a restricted environment possible. An incorrect estimate of this information can result in a substantial economic penalty for the growers. This could happen with the selection of improper sizes of heating, cooling, and ventilation systems. The over size design, for instance, leads to increase cost of production, while under estimating the size of these systems affects the efficiency of production and hence reduces the total return.

The Midwest plan service (MWPS 1983) presented calorimetric data for many farm animals as function of their inside environment. The summary of data for dairy and sheep (10 cm fleece thickness) were presented in Table1. The range of inside air relative humidity used for dairy varied from 55% to 70%, while it was for sheep from 45% to 54%. However, heat and moisture produced in a livestock facility under actual production conditions may differ from laboratory determined data due to

Table 1. Latent and sensible heat losses from dairy (kcal/454 kg body weight) and sheep (kcal/m^2 of body surface area)

Tempe., °C	Latent heat		Sensible heat		Total heat	
	Dairy	Sheep	Dairy	Sheep	Dairy	Sheep
0	220	–	730	---	950	–
5	250	–	650	---	900	–
10	280	18	600	38	880	56
15	310	22	550	33	860	55
20	350	28	430	28	780	56
25	430	28	310	24	740	62
30	–	47	--	16	--	63

evaporation from manure surfaces and waters. Moreover, it is commonly recognized that either extremely hot (Ittner *et al.* 1958) or extremely cold (Webster *et al.* 1970, Christison and Milligan 1974) conditions affect performance, but there is little experimental evidence of environmental effects under production conditions. Since the ventilation system must operate under actual livestock production conditions, heat and moisture production data used in design of these systems should be determined under similar production conditions.

This study was established with the following objectives:

1. Determine total heat and moisture production for growing dairy heifers and sheep under actual production conditions.
2. Determine the efficiency in converting feed intake to body weight under actual production conditions.

Data Collection

Growing dairy heifers (Holstein) averaging 100 to 300 kg and sheep (Naeimi) averaging 20 to 55 kg were used in this study. The experiments were conducted in the Agricultural Experimental Station at Alisha, King Saud University. The research facility having a volume of about 60 m^3 and a floor area of 21 m^2. Both the window and the door of the room were tightly closed and no air infiltration was assumed. No one was also allowed to enter the facility during the experiment except for only 20 minutes every morning and afternoon for feeding and manually clean up. The facility had 30 cm cement brick for walls and 10 cm reinforced concrete slab for ceiling. The thermal conductivities were assumed 20 and 23 (W/m.°c) for cement brick and concrete respectively (Holman 1981). The heat transfer coefficients for inside and outside the facility were assumed 8.35 and 33.39 (W/m^2.°c) respectively (MWPS 1983). The facility floor was of concrete type with gutters. Four pens with slotted floors were placed inside the facility. Each pen had 2 m long and 1.1 m wide. The pens occupied 8.8 m^2 of the floor area, while the rest was left for working space. Four heads were mostly used in each experiment with one head per pen. A schematic diagram of the facility is shown in Figure 1.

Six experiments with three replicates per experiment were conducted to determine the sensible heat, latent heat, and total heat produced inside the facility for both dairy heifers and sheep. Three experiments were conducted for each kind of animals. The number of heifers used was four animals (with an average weight of 96.1 kg/animal), four animals (196.5 kg/animal), and two animals (304 kg/animal) for the first,second, and third experiment respectively. The number of sheep used was four animals (19.7 kg/animal), three animals (35.8 kg/animal), and four animals (52.3 kg/animal) for the fourth, fifth, and sixth experiment respectively. The seventh

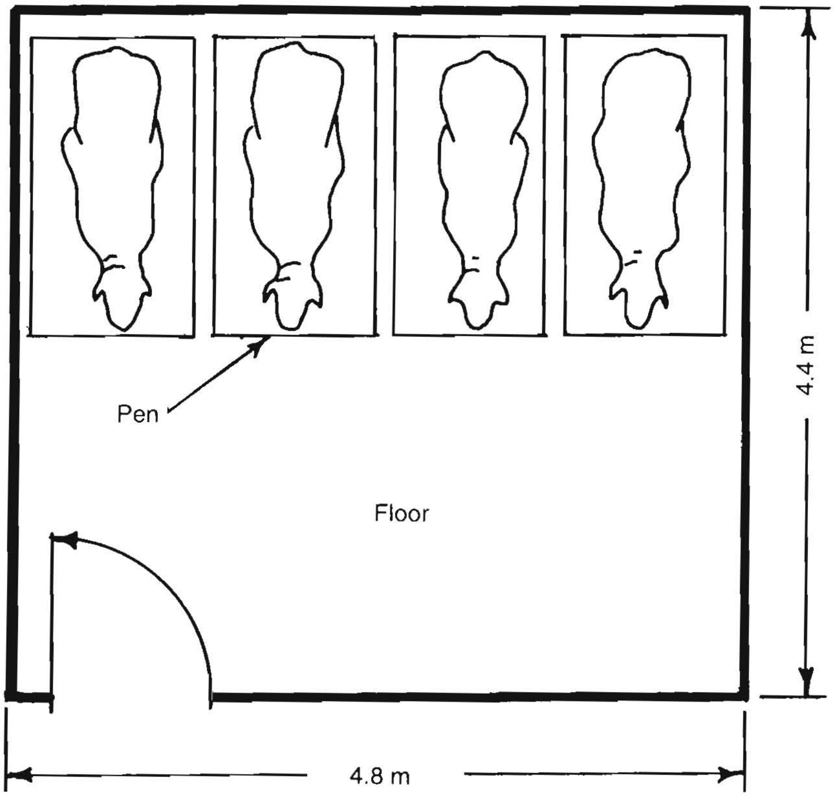

Fig. 1. A schematic diagram for the facility.

experiment, with also three replicates per experiment, was conducted to study the effect of fleece thickness on sheep sensible and latent heat losses. The same animals in the sixth experiment (after sheared) were used in this trial. The room was cleaned and naturally aerated for 2 days between each two consecutive experiments. Each experiment lasted 4 days. The animals were held in the room for one day for acclimation before the trials began.

Daily gain, feed intake, water consumption, and efficiency (kg of gain per kg of feed) were also determined. The animals were fed a standardized feed ration consisting of fresh high - quality alfalfa, sun dried alfalfa hay, and commercial concentrates (18% protein). They were fed twice daily and water was constantly available. The animals and feeders were weighed daily. Water consumption was also measured on a daily basis.

Two units of recording thermographs and hygrothermographs were used to obtain continuous records of psychrometric properties such as air temperature and relative humidity. They were placed in the facility 1m above the floor near the center. This location had been checked previously and found to give readings that were representative of air temperatures and humidities at the animal level. Data were collected from each unit and the averages were determined. The inside air temperatures recorded throughout the different experiments varied from 26 to 34°C, while the inside relative humidity varied from 68 to 85%. No such controls were made for either air temperature or humidity except for ventilation since the purpose was to collect data under actual production conditions. An example of the 24 hour variations of air temperature and relative humidity is shown in Figure 2.

It is worthwhile to mention that the high relative humidity could create a vapor pressure difference that forces water vapor out through the components of the enclosure. Water vapor transfer is not a problem as long as the saturated vapor pressure gradient within the enclosure components remains above the actual vapor pressure gradient (ASAE Stdd, 1987). The psychrometric properties of outside air were also recorded continuously. Another unit of thermograph and hygrothermograph was placed in outside yard in front of the facility and was shielded from direct rays of the sun with an aluminum. Air space was allowed between the aluminum and the unit to avoid erronous heating effects due to solar radiation. The data of the thermographs and hygrothermographs were compared with dry and wet bulb thermometers in five different times throughout a day. The error of air temperature readings was within ± 2°C, while the error of air relative humidity readings was ± 3%.

The capacity of the exhaust fan used for ventilation was $3m^3$/min and no air was recirculated. Ventilation air flow rate was measured with an anemometer. The average of five point measurements was taken at different sites of the cross - section of the fan outside to represent the reading of the air flow rate. The static pressure on the fan outside for Riyadh area was 1011.2 millibar. A correction for the atmospheric pressure was made and the error of the anemometer readings was 0.2%. The manual of the anemometer recommended also a reading correction for air temperature equal to 1% per 10°C temperature difference.

Data Analysis

Heat and moisture balance equations recommended by both American Society of Agricultural Engineers (ASAE) Standards (1987) and MWPS (1983) were used to determine the sensible heat and moisture production rates inside the enclosure. The sensible heat balance in the building is:

$$Qs + Qm = Qb + Qv + Qe \qquad (1)$$

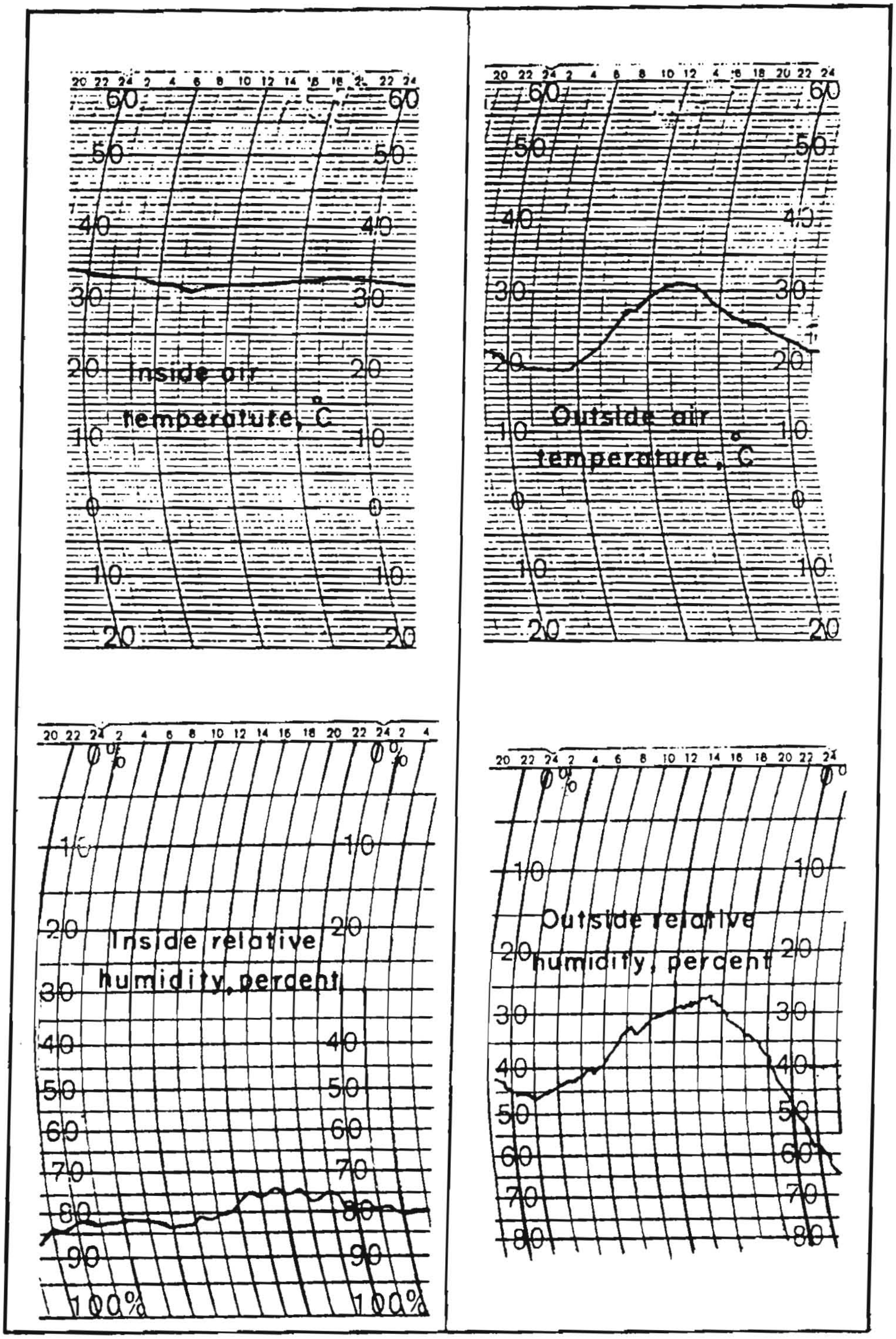

Fig. 2. An example of the 24 hour variations of air temperature and relative humidity.

where

Qs : sensible heat loss rate from animals, J/s

Qm : heat production rate by equipment, *i.e.* motors, lights, *etc.*, J/s (this term is neglected because it is relatively small).

Qb : building heat loss through doors, walls, *etc.*, J/s

Qv : sensible heat loss in ventilating air, J/s.

Qe : sensible heat used to evaporate water, J/s.

The term Qe is usually neglected based upon the fact that some of the sensible heat produced by the animals is used to evaporate water within the structure (MWPS, 1983). The moisture balance in the enclosure is determined as:

$$Ma\,(H_2 - H_1) = Wa + We \quad \text{.........} \quad (2)$$

Where

Ma : ventilating rate, kg da/hr.

H_1 : water vapor in incoming air, kg water/kg da.

H_2 : Water vapor in exhaust air, kg water/kg da.

Wa: water vapor from animals, kg water/hr.

We: water vapor from surface water evaporation, kg water/hr.

da : dry air.

Moisture produced by evaporation, We, can be estimated, but it is usually included in Wa (MWPS 1983).

The calculations of the enclosure heat and moisture balance were performed on hourly basis using equation (1) and (2). They included the use of the actual data of inside and outside air temperatures, inside and outside relative humidities, and specific volume of inside air (fan used is of exhaust type). The inside and outside humidity ratios and the specific volume were determined from the psychrometric chart. A daily average value of sensible and latent heat production rates were determined and plotted using the twenty four hourly values per day. The daily averages were used to develop regression equations to predict the sensible heat and moisture production. Equations for total heat production were also developed by converting the moisture production to latent heat and added to the sensible heat. Regression molels were fitted to the data and only those significant terms ($p<0.05$) were retained.

The efficiency of food digestion is mainly affected by weight, breed, environmental conditions, sex, and feed ration. It is defined as kg of body weight gain per kg of feed intake. The feed efficiency reflects net metabolizable energy conveyed into weight gain under given environmental conditions. Energy obtained after feed digestion is mainly split into two main parts: Energy produced in phase of sensible and latent heat and energy required for mostly body weight gain. The frist phase of energy should be minimized by allowing comfortable conditions in order to increase body weight. The efficiency was daily determined and averaged throughout the entire period of each experiment.

Results and Discussion

Dairy and sheep as homeothermic animals maintain nearly constant body temperature by balancing internal heat production and heat loss to the surroundings. Data of sensible heat, moisture, and total heat produced inside the facility were plotted for growing dairy heifers in Figure 3. The sensible heat produced in the enclosure is defined as the sum of animal sensible heat losses minus the portion of that heat which used to evaporate moisture from the manure surfaces and waters. The quantity of moisture production in the enclosure is the sum of both the respired moisture by animals and moisture evaporated from manure surfaces and waters. Heat losses were expressed per unit body weight rather than per unit body area because of the difficulties in measuring body area. Corresponding average inside air temperature and relative humidity throughout the experiment were 28°C and 70% respectively. Generally speaking, heat and moisture production per unit body weight linearly declined as dairy heifers grew. The quantity of heat emitted is more likely related to weight, breed , psychrometric properties of air, and level of nutrition. As can be seen, the sensible heat produced, for instance, decreased from an average of 180 to 100 Watt/100 kg as heifers body weight increased from roughly 98 to 305 kg. The total heat production which is the sum of both the sensible heat and moisture in the latent heat phase decreased from not far off 278 to 152 Watt/100 kg or 45%. Moreover, total heat at 200 kg ranged from 238 to 191 Watt/100 kg and averaged 208 Watt/100 kg, while latent heat ranged from 88 to 65 Watt/100 kg and averaged 77 Watt/100 kg. Heat loss by evaporation represented an average of 37% of the total heat production. The quantity of moisture produced depends upon animal weight, water evaporated from the floor and waterers, and psychrometric properties of air. It would seem that the heifers were not under neither cold or heat stress.

Regression equations were developed to predict the sensible heat, moisture, and total heat produced as function of animal body weight. The regression equations were presented with their corresponding correlation values. No other terms except the linear ones were significant ($p<0.05$). It should be mentioned that extrapolations beyond the covered range are not permissible.

$$Qs = 213.5 - 0.377\ (Aw), \qquad R^2 = 0.85 \quad \text{(3)}$$

$$M = 0.184 - 3.56*10^{-4}\ (Aw), \qquad R^2 = 0.83 \quad \text{(4)}$$

$$Qt = 332.6 - 0.603\ (Aw), \qquad R^2 = 0.88 \quad \text{(5)}$$

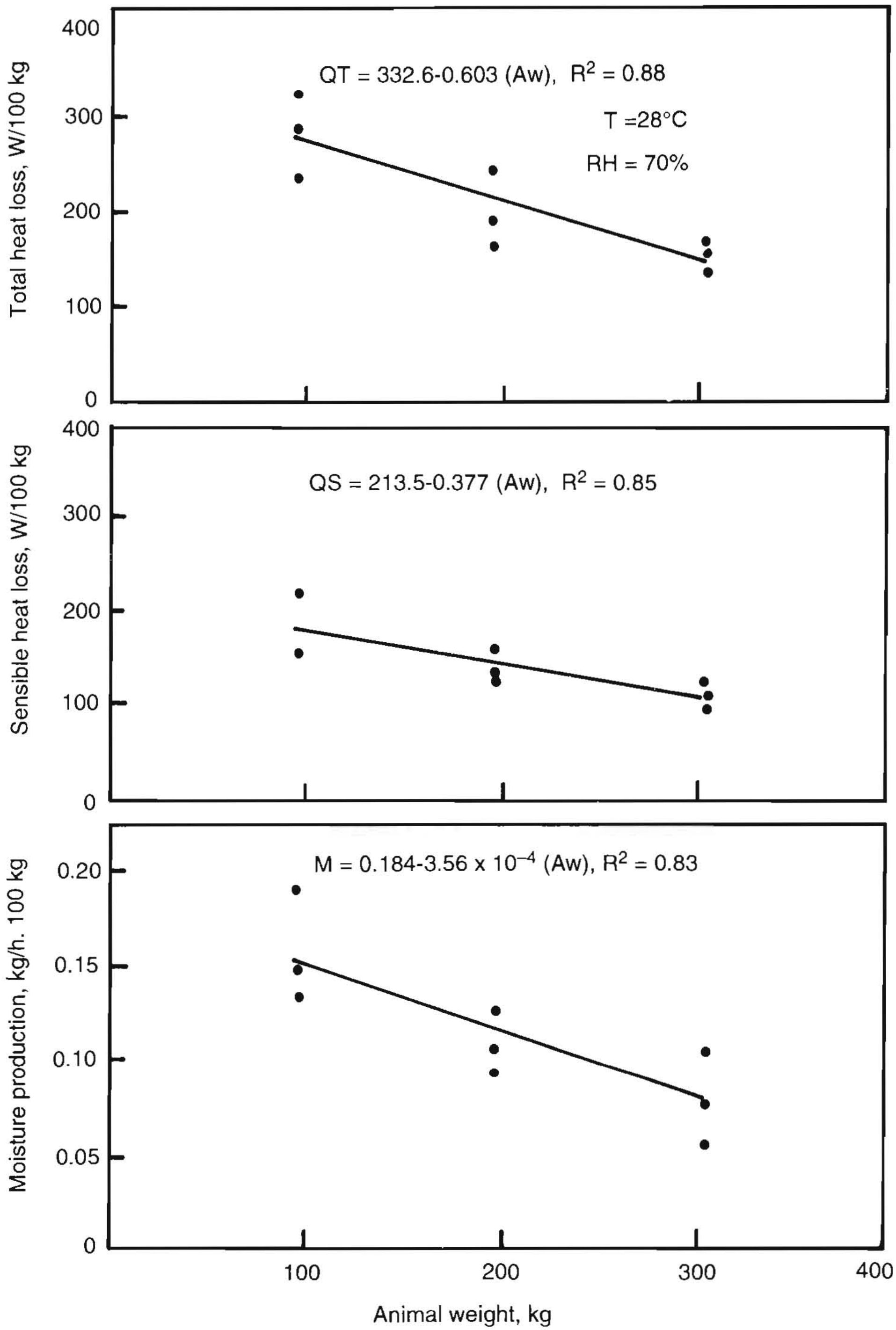

Fig. 3. Heat and moisture losses of dairy heifers .

where

Qs : sensible heat produced, Watt/100 kg.
M : Moisture produced, Kg/h.100 kg.
Qt : total heat produced, Watt/100 kg.
Aw : animal body weight, kg.

The sensible heat, moisture, and total heat produced for sheep are also shown in Figure 4. The sensible heat produced per unit body weight decreased from 2.7 to 0.6 Watt/(kg body weight), While the moisture produced decreased from11.7 to 5.9gm/(h.kg). This occurred as sheep grew from 20 to 53 kg. In addition, the total heat produced decreased from 10 to 4.3 Watt/kg. Equations (6), (7), and (8) were also developed to predict the sensible heat, moisture, and total heat produced for sheep respectively. The predictions should only be carried out within the covered range.

$$Qs = 3.94 - 6.53*10^{-2} (Aw), \quad R^2 = 0.89 \quad (6)$$

$$M = 14.786 - 0.176 (Aw), \quad R^2 = 0.92 \quad (7)$$

$$Qt = 13.167 - 0.175 (Aw), \quad R^2 = 0.94 \quad (8)$$

where

Qs : sensible heat produced, Watt/kg.
M : moisture produced, gm/h.kg.
Qt : total heat produced, Watt/kg.

The effect of body covering or fleece thickness on sheep sensible and latent losses were presented in Table 2. Fleece thickness affected all method of heat transfer. The sensible heat loss comes mainly from convection and radiation, while the latent heat was due to evaporation and respiration. Sheep are usually subjected to heat stress at temperatures slightly above 30°C. Stressing temperatures are more

Table 2. Effect of fleece on sheep sensible and latent heat losses

Replicate	Fleece (9 cm)			Fleece (0.4 cm)		
	Sensible heat W/kg	Latent heat W/kg	Total W/kg	Sensible heat W/kg	Latent heat W/kg	Total W/kg
1	1.1	2.93	4.03	2.27	1.86	4.13
2	0.25	4.27	4.52	2.84	1.54	4.38
3	0.43	3.95	4.38	0.53	1.76	2.28
Avg.	0.59	3.72	4.31	1.88	1.72	3.6

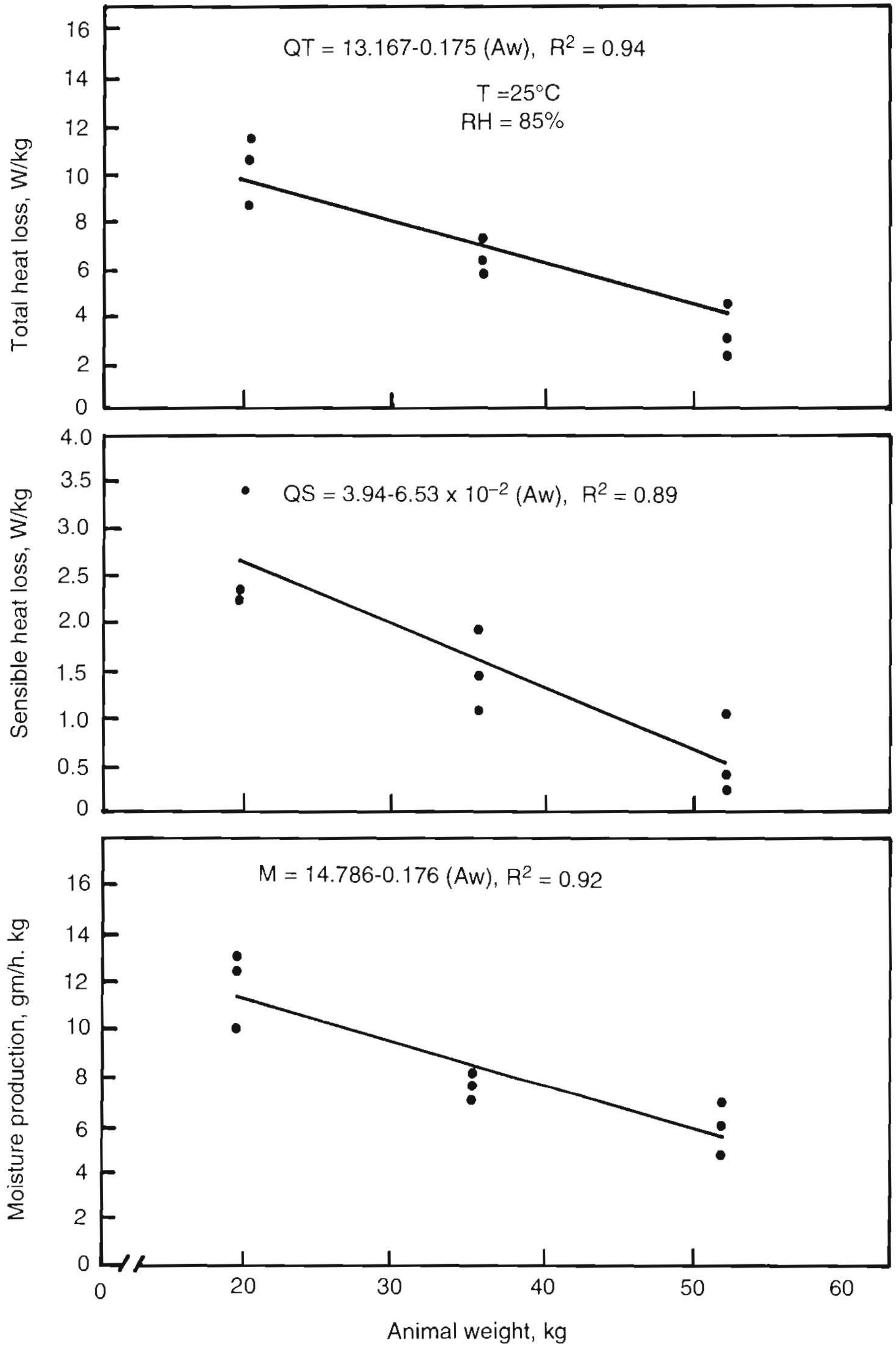

Fig. 4. Heat and moisture losses of sheep.

likely influenced by body covering. As can be seen from the table, the sensible heat loss increased from 0.59 to 1.88 Watt/kg as fleece were sheared from 9 to 0.4 cm and consequently the latent heat loss decreased from 3.72 to 1.72 Watt/kg. This was eventually acceptable since the animals are to maintain homeothermy. However, the increase in sensible heat loss was 1.29 Watt/kg, while the decrease in latent heat was 2.0 Watt/kg. The difference between the last two figures affected the total heat loss to decrease from 4.31 to 3.6 Watt/Kg. The drop of total heat loss could be associated to the variations of the uncontrolled inside environmental conditions between the two experiments concerning the study of the fleece effect. The sensible heat loss from animal body area, with 9 cm fleece, represented almost 14% of the total body heat loss. This ratio increased to 52% as fleece were sheared to 0.4 cm. It is quite obvious that the body covering affected on percentages of sensible heat losses as well as latent heat losses.

Growth rate and feed efficiency per animal is presented in Table 3. The feed efficiency is defined as kg of body weight gain per kg of feed. It reflects the net metabolizable energy converted into weight gain. All animals in all covered stages were fed the same type of feed and quality. Each figure in the table represents the average data of four animals and three replicates. As can be seen, the feed efficiency decreased from 0.41 to 0.11 as heifers grew from 98 to 305kg, while the drop was from 0.33 to 0.16 as sheep grew from 20 to 53kg. The differences in feed efficiency among dairy heifers and sheep were due to different breed and weights. The water consumption was also presented in Table 3. The feed intake - to - water consumption ratio was dtermined for both dairy heifers and sheep. The overall ratio was 20% and 30% for heifers and sheep repectively.

Table 3. Daily growth and feed efficiency per animal

Weight, kg	Feed intake, kg	Water consumption, kg	Weight gain, kg	Gain per kg feed
Heifers				
98	2.53	13.46	1.03	0.41
134	2.34	15.57	0.94	0.40
193	3.46	17.53	0.85	0.25
305	6.29	22.65	0.67	0.11
Sheep				
20	0.61	2.2	0.20	0.33
30	0.98	2.45	0.333	0.34
36	1.02	2.43	0.308	0.30
51	1.26	5.5	0.312	0.25
53	1.29	4.65	0.208	0.16

Conclusions

1. Total heat production linearly decreased for heifers from 278 to 152 Watt/100 kg as they grew from 98 to 305 kg.

2. Total heat produced by sheep linearly declined from 10 to 4.3 Watt/kg as body weight increased from 20 to 53 kg.

3. Heat loss by evaporation represented an average of 37% and 68% of the total heat produced by heifers and sheep respectively.

4. The percentage of sensible heat loss increased for sheep from 14% to 52% as fleece were sheared from 9 to 0.4 cm.

5. The feed efficiency decreased for heifers from 0.41 to 0.11 as they grew from 98 to 305 kg and decreased for sheep from 0.33 to 0.16 as they grew from 20 to 53 kg.

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الحرارة والبخار المتولدان من عجلات الأبقار والأغنـام

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تم إجراء سبعة تجارب على عجلات أبقار الهولستين وذكور الأغنام النعيمي لإيجاد الحرارة والرطوبة المتولدة وكفاءة التمثيل الغذائي تحت ظروف إنتاج فعلية . وقد وجد أن الحرارة الكلية المتولدة من العجلات تتناقص تناقصاً خطياً من ٢٧٨ إلى ١٥٢ وات/ ١٠٠ كجم وذلك عند ازدياد الوزن من ٩٨ إلى ٣٠٥ كجم . بينما تناقصت الحرارة الكلية للغنم من ١٠ إلى ٣ ,٤ وات/ كجم نتيجة للنمو من ٢٠ إلى ٥٣ كجم . وقد وجد أن الحرارة المفقودة بالبخر تمثل ٣٧٪ و ٦٨٪ من الحرارة الكلية المفقودة وذلك بالنسبة لعجلات الأبقار والأغنام على الترتيب . وقد تم تطوير عدد من معادلات الأرتداد الخطي للتنبؤ بالحرارة المفقودة من سطح جسم الحيوان كدالة في وزنه . تم أيضاً بالنسبة للأغنام دراسة تأثير فروة الجسم أو سمك الصوف على الحرارة المفقودة من على سطح الجسم . وقد زادت نسبة الحرارة المحسوسة إلى الحرارة الكلية من ١٤٪ إلى ٥٢٪ وذلك بعد قص طول الصوف من ٩ إلى ٤ ,٠ سم . وقد وجد أيضاً أن معدل الأستفادة الغذائية تنخفض من ٤١ ,٠ إلى ١١ ,٠ (كجم نمو/ كجم علف) عند زيادة وزن العجل من ٩٨ إلي ٣٠٥ كجم ، بينما كان الأنخفاض من ٣٣ ,٠ إلى ١٦ ,٠ (كجم نمو/ كجم علف) وذلك عند زيادة وزن الأغنام من ٢٠ إلى ٥٣ كجم .