WIND CHILL EFFECT FOR CATTLE AND SHEEP

by

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Chapter I

INTRODUCTION

Energetic efficiency of livestock exposed to decreased effective temperatures resulting from combinations of cold temperatures and wind is lowered. The term "effective temperature" is used to describe the cumulative effect of all environmental variables on animals. When the wind effect in particular is described it is known as the wind chill effect. Methods for predicting performance, maintenance requirements, and other facets of energy utilization, are only valid under defined environmental conditions which are difficult to describe and nearly impossible to duplicate. For example, the net energy system (NRC, 1963) now used for determining ration requirements and for predicting performance of feedlot cattle does not account for environmental variations such as cold and wind. If adjustments were available to compensate for the wind chill effect, the prediction of energy retention, maintenance requirements, and severity of cold stress would be of more value to stockmen.

A wind chill index for human beings (bare-skinned animals) has been developed and is now in use by the weather bureau for predicting the effective temperature during cold, windy, conditions. Although such an index is useful for humans, its application to animals with natural coverings (i.e. hair or wool) is questioned.

The goal of this research was to investigate the effect of cold and wind on cattle and sheep using a model system comparing the rate of heat loss through representative hides and pelts. The validity of using human wind chill index for cattle and sheep was tested by comparing it with the results obtained.

Chapter II

LITERATURE REVIEW

Homeotherms exposed to temperatures below the thermoneutral zone (cold stress) respond by increasing heat production and minimizing the rate of heat loss. A reduction in the rate of heat loss improves energetic efficiency by lowering the energy requirement for maintenance. Avenues of heat loss during cold are radiation, conduction, convection and evaporation. Respiratory evaporation during cold is obligatory and cannot be effectively controlled. The remaining three sensible avenues of heat exchange can be regulated to some extent by either behavioral or physiological adjustments.

Variables affecting the rate of sensible heat loss are temperature gradient, fluid velocity, radiation characteristics of the surface, and thermal conductance. Collectively, these variables should be combined to offer an effective temperature which reflects the cooling power of the environment. The establishment of an effective temperature would allow more accurate predictions of animal performance, maintenance requirements and general severity of cold stress. The present practice of using dry bulb temperature to quantitate cold stress is inaccurate.

The cooling power of the environment must account for the animal's ability to adjust to cold; in general, the homeotherm's physiological responses to cold are to reduce the conductance (commonly referred to as its reciprocal, increased insulation). Insulation is afforded the animal as follows:

a) Tissue insulation (I_t) is provided by the skin, subcutaneous fat and other tissues. Homeotherms control tissue insulation by vasomotion.

b) External insulation (I_e) is provided by hair or wool. Piloerection rapidly increases the barrier to heat flow in some cases; however, domestic livestock increase hair or wool growth over a relatively long period of time.

c) Air interface insulation (I_a) is an insulatory barrier provided by the layer of air over any surface. Homeotherms have no physiological control over I_a.

These three components are additive with the destruction of any one resulting in less total insulation. Of the environmental variables affecting an effective temperature during cold, the one which directly alters insulatory barriers is wind. It is logical to assume that the development of an effective temperature will first require the establishment of a wind chill effect.

Methods for estimating the effect of wind chill include the use of calorimeters, respiration chambers, and psychrometric rooms (Webster, Hicks and Hays, 1969). These methods base their observations on the production efficiency and physiological responses of the live animals, but do not measure actual heat flow. The heat lost through the animal's natural insulation must be measured and studied to determine the combinations of temperature and wind which cause the greatest degree of heat loss due to destruction of insulatory barriers.

Out-of-doors environmental conditions can be quite different than the environment of a respiration chamber; variables include type of wind, solar radiation, infra-red radiation and moisture precipitation. Blaxter, 1962, hypothesized, "the question to ask is not whether the calorimetric experiments are applicable out-of-doors, but rather the extent to which the thermal insulation of the animal changes in response to the separate attributes of climate, and whether quantitative estimates of these changes can be made."

The United States Army developed a wind chill index for humans by observing the time necessary for a plastic bag filled with water to freeze when subjected to cold and wind combinations. By comparing the rate of freezing at calm conditions with that observed with various wind velocities, equivalent conditions were reported (Sipple and Passel, 1945).

Treagear (1965) designed an apparatus for measuring heat loss through excised portions of swine, horse, and rabbit pelts. The effect of wind velocities of 0 - 18 mph were studied on pelt sections taken from the back, belly and flank of these animals. Winds were found to increase the rate of heat loss, but this loss was dependent on the density of the hair involved.

Webster (1971) designed a model cow for determining heat losses from cattle exposed to cold outdoor environments. The unit, MOOCOW (Model Ox Observing Cold Outdoor Weather), was constructed of roughened black plaster of paris and was the size and shape of a 250 kg calf. An ethylene glycol solution warmed by a heated water bath was circulated through a series of copper pipes running under the surface of the trunk and extremities of the model. The power consumption necessary to maintain a constant temperature (39°C) was used to estimate the heat loss from the model. Attempts to account for I_E were calculated. The results of this study indicated that wind was related to heat loss in MOOCOW by the equation:

$$H = \frac{39.0 - T_A}{18.56 - 0.44\sqrt{V}}$$

where: H = heat loss (Kcal/m^2/24 hr.)

T_A = ambient temperature (°C)

V = wind velocity (m/min)

It has been shown experimentally (Joyce, Blaxter and

Park, 1966) that I_a for sheep can be described using the following equations:

$$I_a = \frac{1}{0.115 + 0.099\ V^5}$$

where: V = air velocity (mph)

Joyce and Blaxter (1964) found that to work with the air interface insulation and external insulation separately is incorrect except under still air conditions. Therefore, external insulation must deal with total external insulation, $I_E + I_A$, with values obtained at fleece lengths of zero regarded as estimates of I_A.

Research has shown that cold ambient temperatures compounded with wind resulted in increased maintenance requirements and less efficient gains. Blaxter and Wainman (1964) found that winds as small as 0.4 - 1.6 miles per hour increased heat production in cattle by 6% during freezing conditions. They also reported that ambient temperature alone had no statistically significant effect on external insulation, but that wind reduced it markedly. Webster, Hicks and Hays (1969) found that a constant cold environment did produce an increase in heat production which could be related to the intensity of cold stress to which sheep were exposed. Sheep kept outdoors during cold winter weather for 6 months increased their heat production from 110 to 128 Kcal/Kg^{3}/4/day. Hidiroglou and Lessard (1970) reported that steers exposed to natural extremes in weather (October - April) gained 25.2Kg less per animal than those protected from extremes.

Their work agreed with findings of Lenschow (1959) and Muller (1956). Williams (1958) has found that protection from high winds is advisable to reduce maintenance costs. Also, since most livestockmen base their conception of the degree of cold stress on the wind chill index designed for humans, it is possible that the level of nutrition fed as a basal ration is too high. Under more severe conditions, however, recommended nutritive levels become quite insufficient. Hidiroglou and Lessard (1970) reported that daily nutrient requirements for 275 - 365 Kg wintering yearling steers proved to be nearly 50% greater than the 1963 NRC recommendations when animals are subjected to cold winter conditions (-43°C to -13°C). The present system used for the prediction of gains by feedlot animals (Net Energy System) does not account for temperature differences. As more work is done to provide effective temperatures there will be need for specific chill indices for livestock. Webster's index (1971) is a start but an index which considers the properties of natural insulation must be developed. As more is learned about the effect of cold and wind on the insulatory breakdown of the animal's natural covering, it could prove beneficial to develop a specific wind chill index for animals. One index could broadly cover all species of livestock.

Chapter III

WIND CHILL EFFECT FOR CATTLE AND SHEEP

Introduction

Lowered energetic efficiency resulting from increased maintenance requirements of livestock exposed to effective temperatures[1] below the thermoneutral zone have been reported (Blaxter and Wainman, 1964; Williams and Bell, 1964; Webster, Chlumecky and Young, 1969; Webster, Hicks and Hays, 1969; Hidiroglou and Lessard, 1970). Major variables which contribute to reduction of effective temperature during cold stress are dry bulb temperature and wind velocity. Effective temperature is not similarly related to both wind and cold but instead is affected by combinations of the two, commonly referred to as the wind chill effect. Severity of cold stress for humans is predicted by a wind chill index used by the United States Weather Bureau and originally prepared for the Army by Sipple and Passel (1945). This index predicts the cooling power of cold and wind combinations for bare-skinned animals but may not be valid for animals with external insulation such as hair or wool.

Controlled studies relating the cooling effect of combinations of dry bulb temperature and air velocity on domestic

1 Effective temperature is used to rate the cooling power of the physical environment in terms of dry bulb temperature.

animals have been reported (Thompson et al., 1954; Tregear, 1965; Webster, 1971). It was the goal of this study to determine the effects of cold temperatures combined with air velocity on the rate of heat loss through different hides and pelts using a model system and to offer a prediction equation for the rate of heat loss. This equation will be compared to that for bare-skinned animals to test the validity of the human wind chill index for estimating cold stress to animals with hair or wool.

Experimental Procedure

A model system was developed to estimate the rate of heat loss through hide and pelt sections exposed to combinations of dry bulb temperatures ranging from -23°C to +2°C and wind velocities from 0 through 35 miles per hour. A constant temperature circulating water bath (15 cm wide X 17 cm high X 12 cm from front to back) maintained at 39°C served as the heat source. The bath was constructed of ¼" lucite plastic sheets insulated with styrofoam on all but one side, which was made water tight by glueing a thin plastic film (Saran Wrap) over the entire side. Hide and pelt sections (28 cm X 23 cm) were placed over the film-covered side of the water bath and held tightly in place by a lucite plastic template (Fig. 1).

Heat flow through the hide or pelt section was measured by an RDF #20460 heat flow sensor and a Kiethly Model 860

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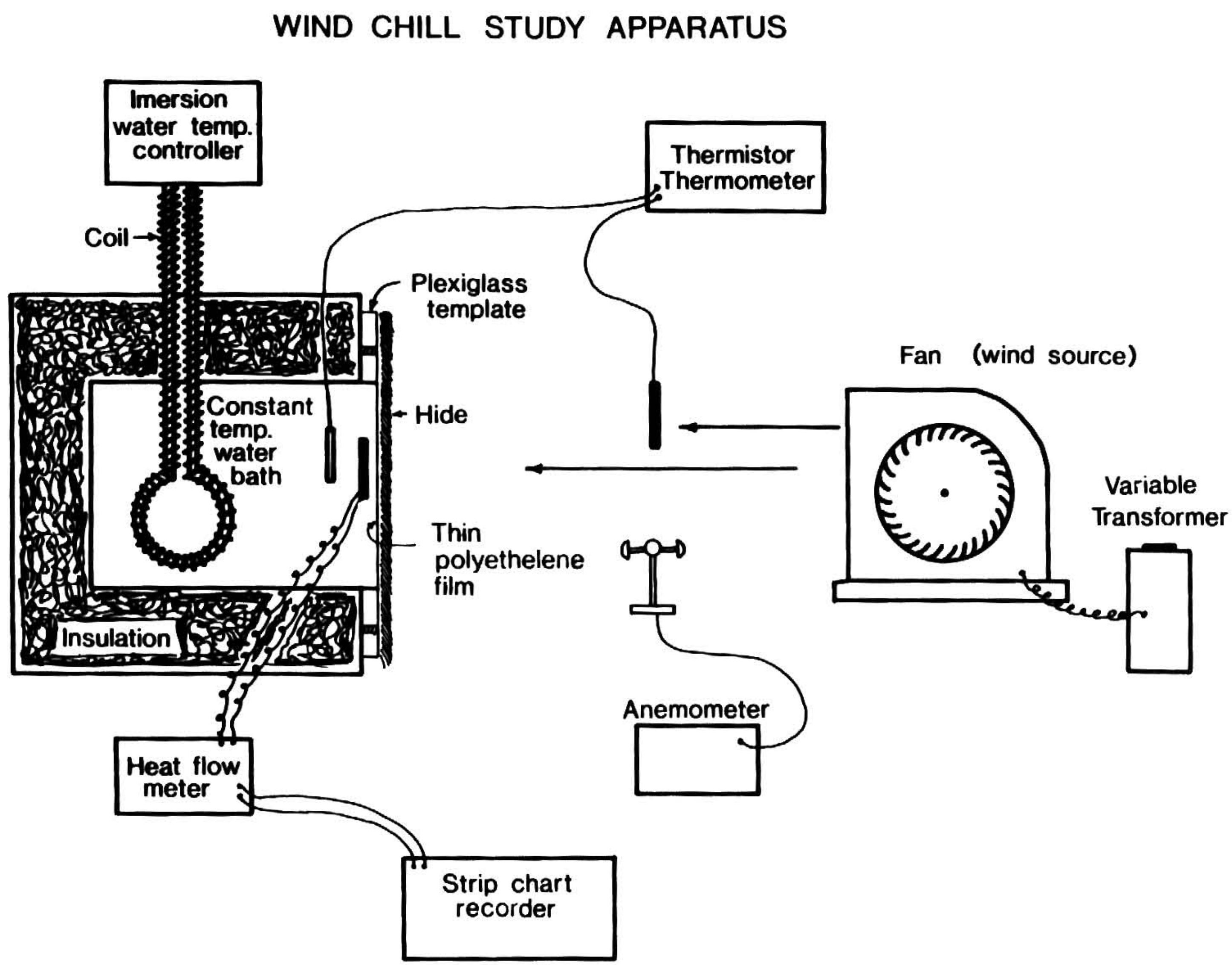

Figure 1. Schematic of wind chill study apparatus.

read-out system. The sensor was located between the plastic film and the hide or pelt section. Air temperature was measured with a YSI Model 8438 thermistor probe located approximately 10 cm from the hair or wool surface. Wind velocity was determined using a Hastings air meter Model RB-1. Air velocities were created with a squirrel cage fan connected to a variable transformer. Various walk-in freezers, coolers and ambient conditions were used to obtain experimental temperatures. In all cases the entire model system was placed in the cold environment and protected from any natural air velocities which may have been present.

The experimental plan involved 210 observations on four cattle hides and two sheep pelts at five temperatures (-23, -18, -12, -7 and +2^{o}C) and seven wind velocities (0, 5, 10, 15, 25, 30 and 35 mph). These data were graphed and statistically analyzed by comparing to linear, quadratic and cubic models.

Results and Discussion

The rate of heat flow from animal to cold environment is partially dependent on the insulatory barriers provided by the air interface (I_a), the external insulation provided by hair or wool (I_e) and the tissue insulation afforded by the skin and tissue (I_t). These insulatory barriers are additive and during cold stress are valuable in minimizing the rate of heat loss. The absolute rate of heat flow is largely dependent on the existing thermal gradient which in this case is the difference between deep body temperature and the dry bulb temperature of the environment (Thompson, Worstell and Brody, 1952). Initially, air movement over hair, wool, or the skin surface decreases I_a resulting in a reduction of total insulation and a consequent increase in the rate of heat loss. Any increase in the rate of heat loss whether it be by an increased gradient or by a decrease in insulation results in increased maintenance requirements and ultimately in decreased energetic efficiency.

The rate of heat loss through cattle hides as a function of dry bulb temperature and wind velocity is shown in figure 2. Increased rate of heat loss with increased wind velocity is a non-linear relationship with the rates of heat loss being non-proportionally more rapid at low wind velocities (less than 10 mph) than at high wind velocities (greater than 25 mph). A relatively slower rate of heat loss is evident at velocities between 10 and 25 mph. A non-linear rate of heat flow is expected since a power term involving wind velocities is included in convective heat loss equations; however, the bi-phasic rate observed is not predicted. Apparently, wind further reduces total insulation by affecting I_e particularly during higher wind velocities (greater than 25 mph). This combination of convective heat loss, which can be predicted by the convective heat loss equation, and decreased insulation apparent during air movement, makes

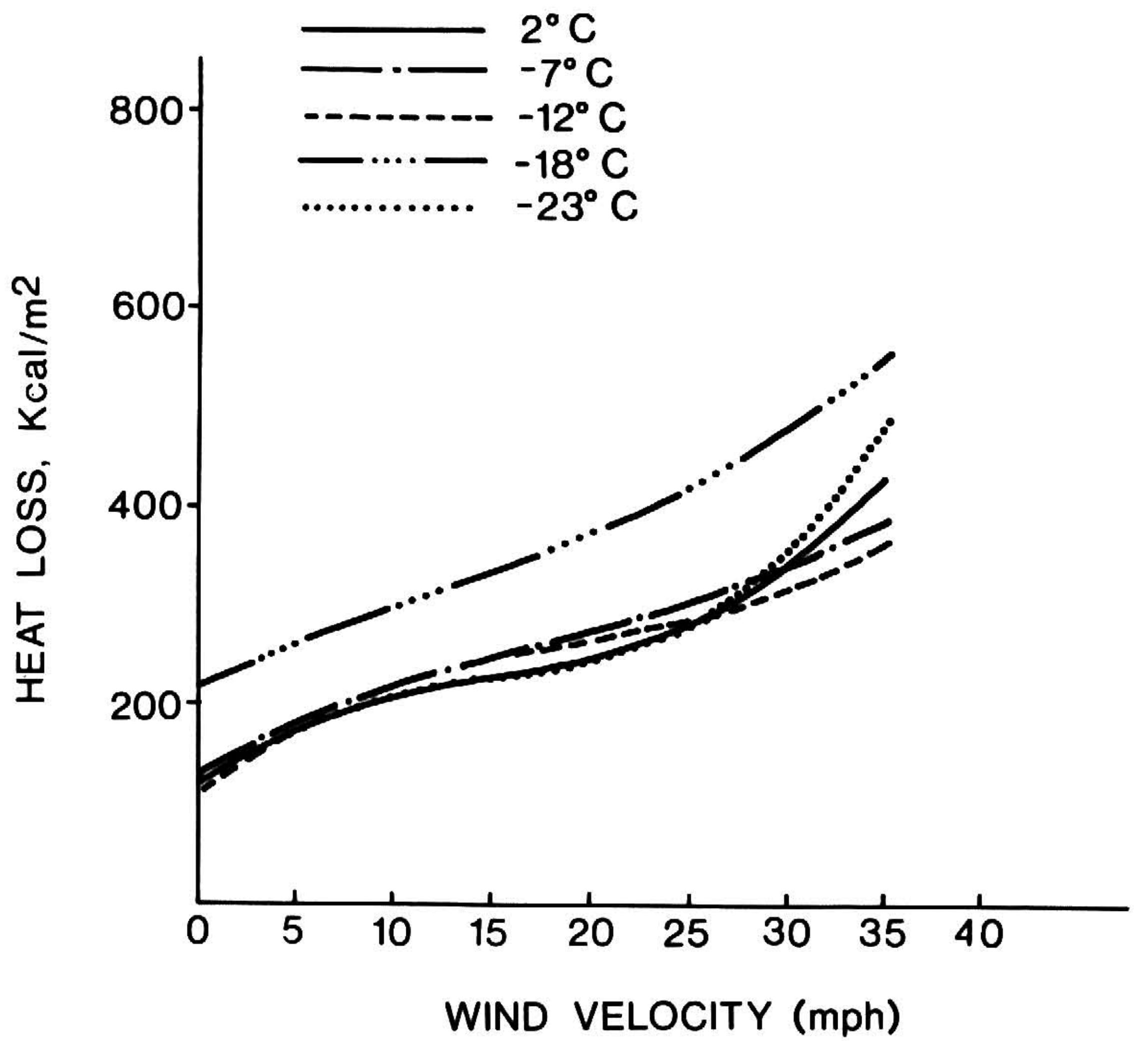

Figure 2. Rate of heat loss through cattle hides as a function of dry bulb temperature and wind velocity.

it difficult to estimate a wind chill effect.

Some discrepancies exist in data presented in figure 2 dealing with the rate of heat loss from different hides and pelts at different ambient temperatures. Higher rates of heat loss are noticed, for example, with smaller thermal gradients which does not coincide with heat transfer equations. It is believed that these differences exist because of destruction of the tissue insulation which occurred during continued freezing and thawing of the hides and pelts between experimental runs. More important than the absolute rate of heat loss represented by these plots is the shape of the heat loss curve depicting a single hide or pelt at a given temperature.

A wind versus heat loss curve from a cattle hide at $10^{o}C$ is compared with the wind chill index used by the weather bureau (Fig. 3). The wind chill index developed by Sipple and Passel (1945) is a quadratic function and when plotted, a relatively rapid rate of heat loss is indicated at low wind velocities with a slower rate of increase at velocities greater than 30 mph. Most descriptions of the wind chill index for humans indicate that wind velocities exceeding 40 mph have little additional effect on heat loss. This exhausted effect of wind is due to a nearly complete destruction of I_a and to a limited rate of conductive heat flow (i.e. small temperature gradient at the surface). In contrast the plot of heat loss rate from the cattle hide increases rapidly from 0 - 10 mph wind velocities then tends to playeau between velocities of 15 and 20 mph but, different than the human wind chill plot, the rate of heat loss increases again at wind speeds greater than 25 mph. The data were adjusted to remove tissue effects by subtracting the insulatory value of the skin without the external insulation and then fitted to both a quadratic and a cubic curve. The hypothesis that the cubic model could not describe the heat loss-wind speed relationship significantly better than the quadratic model was tested using an unequal subclass analysis of variance (Fryer, 1966). This hypothesis was rejected ($P < .01$) and it was concluded that a cubic relationship does exist between heat loss and wind velocity for the animal hides. Therefore, the quadratic relationship wind chill indices for humans does not accurately predict the rate of heat loss resulting from combinations of dry bulb temperature and wind velocity for cattle and sheep; and that the use of the cubic equations is more valid.

Other equations have been used to estimate the rate of heat loss from animals during windy conditions. Thompson et al. (1954) used a linear equation to predict heat loss from a dairy cow during cold, windy conditions:

$$Y_h = 4197 - 1.413t + 19.35v\ (75 - t)$$

where:

Y_h = heat loss from the cow, (Kcal/hr)

v = wind velocity (mph)

t = air temperature ($^{o}C.$)

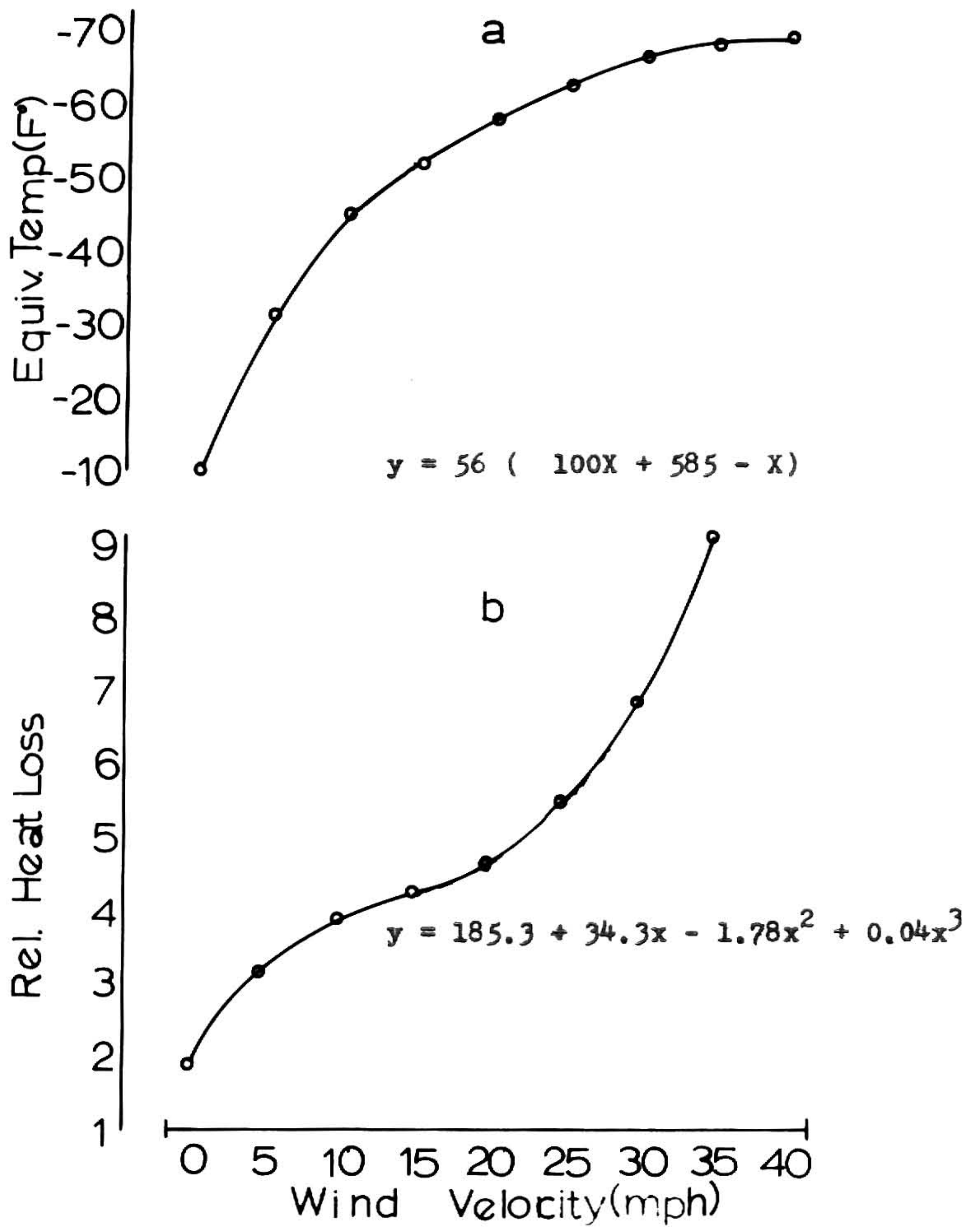

Figure 3. Heat loss curve from a cattle hide (b) compared to the human wind chill index curve (a).

This equation appeared to work well at the air velocities studied (0.4 - 10 mph), but was not studied at higher wind velocities. Data in this experiment would contradict the prediction of the cubic formula at higher wind velocities. Tregear (1965) studied the effect of wind velocity on rate of heat loss through various animal hides using a model system similar to the one described in this experiment. The results of his study indicated a quadratic relationship similar to that of the human wind chill index; however, maximum wind speeds of 18 mph were used; consequently, the second increase in rate of heat loss predicted by the cubic relationship was not obtained. Webster (1971) studied the effect of wind velocity on animal energetics using MOOCOW as a model system. Results of these experiments again indicate a quadratic relationship between rate of heat loss and cold, wind combinations. The model used by Webster, however, did not possess external insulation in the form of either wool or hair and therefore, may not be relevant to animals with hair or wool.

Figure 4 illustrates the hypothesis of findings presented here. During still air conditions, the rate of heat loss is minimized by three insulatory factors: (1) I_t is altered only during vasomotion and is not directly affected by wind velocity; (2) I_e is provided by hair or wool and in most domestic species cannot be changed physiologically in a short period of time; (3) I_a is present on all surfaces and is the

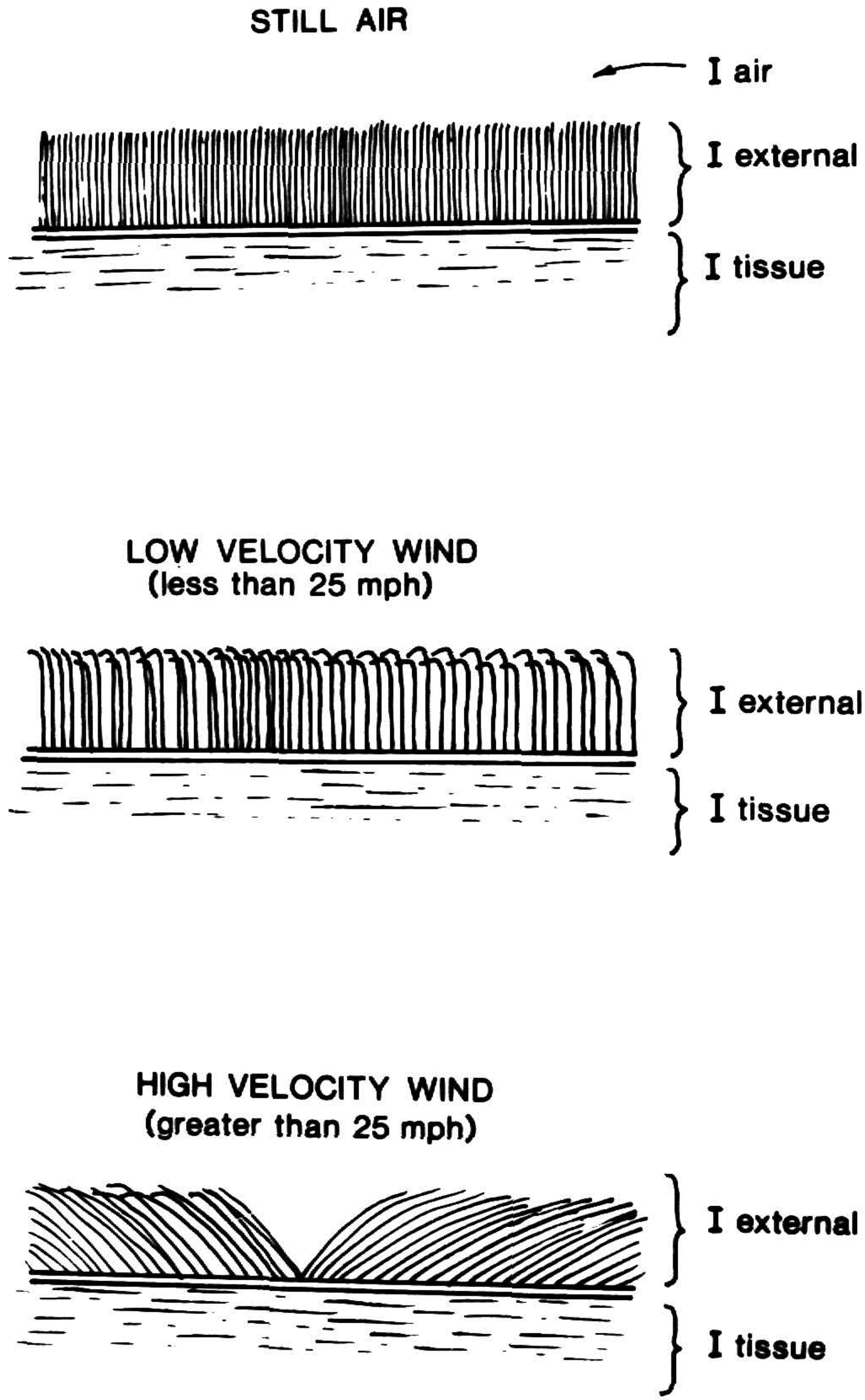

Figure 4. Schematic of structural breakdown of hair or wool.

first insulation destroyed by air movement. During low wind velocities, as illustrated in Fig. 3, the insulation of the air interface is destroyed and consequently, the rate of heat loss increases. It is this destruction of I_a by wind which is apparent in both bare-skinned animals and those with hair or wool. This destruction of I_a is predicted by the human wind chill index (Sipple and Passel, 1945). It should be noted that with low wind velocities (less than 10 mph) there is little alteration of the hair or wool and consequently external insulation is unchanged. During high wind velocities (greater than 25 mph) the existing external insulation is partially destroyed due to a breakdown and/or separation of the hair or wool fibers. This destruction of external insulation by high wind velocities makes animals such as cattle and sheep unique compared to the bare-skinned animal, for it is the destruction which renders the wind chill indices prepared for bare-skinned animals non-applicable for animals with hair or wool. Consequently, the relationship between wind velocity, cold temperatures and the rate of heat flow from animals such as cattle and sheep assumes a cubic relationship rather than the quadratic equation predicted for the bare-skinned animal.

The air velocity necessary to destroy external insualtion of cattle hides or sheep pelts is variable. The pooled data from experimental trials with all hides and pelts is shown in figure 5. It is evident from these plots that the rate

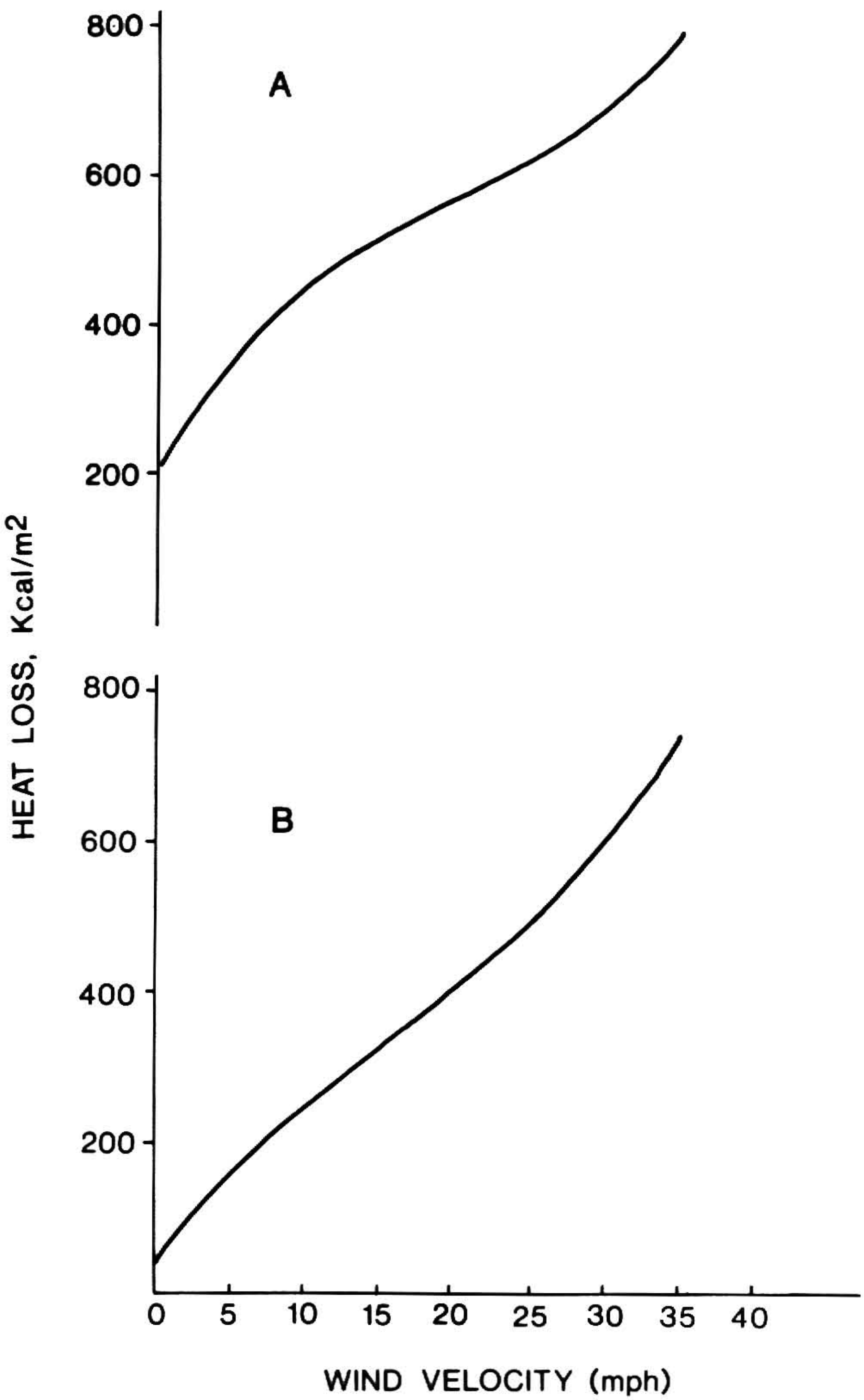

Figure 5. Cattle (A) and sheep (B) heat loss data pooled per species and plotted.

of heat flow through both hides and pelts exposed to wind are similar in terms of response curves. The curvilinear effect is more pronounced for cattle hides compared with sheep pelts with the inflection point for cattle hides occurring at a lower wind velocity. This difference is explained by the fact that hair provides less insulation than wool resulting in a greater rate of heat flow. In addition, the fine-textured, less dense characteristic of hair renders the hides more vulnerable to structural breakdown by lower air velocities. A difference is expected between cattle with dense hair when compared with sparsely covered individuals. The length of hair or wool could also affect the wind velocity necessary for destruction of the external insulation (Berry and Shanklin, 1961). Certainly, additional work is needed to more specifically characterize pelts and hides so that a more accurate prediction of the wind chill effect can be calculated. However, from data presented, it appears that heat loss through animal hides and pelts exposed to various air velocities can be predicted by a cubic equation.

Summary

Increases in the rate of heat loss through animal hides with hair or wool subjected to cold temperatures ($-23^{\circ}C$ to $+2^{\circ}C$) and wind (0 through 35 mph) were measured. The rate of heat loss was not linearly proportional to the increase in wind velocity but instead was more closely related to a cubic relationship. This is different from the quadratic relationship predicted by the wind chill index used by the Weather Bureau (U. S. Govt. Printing Office, 1964). This data would suggest that the wind chill index which is a quadratic function is not valid for animals with natural coverings, particularly at wind velocities greater than 25 mph. Instead, the relationship between rate of heat loss and wind velocity for animals with hair or wool is more accurately predicted by the cubic function which seems to account for the destruction of the external insulation occurring during wind speeds greater than 25 mph.

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A P P E N D I X

APPENDIX TABLE A

Heat Flow Through Excised Hide Section

Hide #1 (Fig. 1A)

Temperature (^{o}C)

Wind Speed (mph)	+2	-7	-12	-18	-23
0	119	122	103	217	122
5	171	185	176	258	157
10	209	217	223	298	217
15	236	242	239	326	239
25	250	304	279	434	277
30	364	347	331	461	358
35	418	385	361	556	488

APPENDIX TABLE B

Heat Flow Through Excised Hide Section

Hide #2 (Fig. 1B)

Wind Speed (mph)	Temperature (°C) +2	-7	-12	-18	-23
0	176	250	271	212	285
5	358	494	497	309	388
10	420	597	597	404	507
15	442	651	678	483	575
25	480	760	814	570	668
30	575	895	923	678	910
35	665	1113	950	792	1167

APPENDIX TABLE C

Heat Flow Through Excised Hide Section

Hide #3 (Fig. 1C)

Wind Speed (mph)	Temperature (°C) +2	-7	-12	-18	-23
0	323	312	304	434	271
5	483	502	450	497	347
10	535	592	559	657	456
15	584	678	624	760	488
25	602	760	706	895	537
30	632	828	787	963	678
35	733	1004	882	1113	841

APPENDIX TABLE D

Heat Flow Through Excised Hide Section

Hide #4 (Fig. 1D)

Wind Speed (mph)	Temperature (C) +2	-7	-12	-18	-23
0	149	157	130	122	130
5	312	266	263	250	225
10	374	345	426	448	407
15	456	421	497	575	559
25	540	556	602	923	700
30	632	722	800	1031	868
35	689	719	895	1140	1302

APPENDIX TABLE E

Heat Flow Through Excised Pelt Section

Fleece #1 (Fig. 1E)

Wind Speed (mph)	Temperature (C) +2	-7	-12	-18	-23
0	41	49	35	62	54
5	133	155	144	168	136
10	242	328	252	426	271
15	315	442	323	570	380
25	483	586	456	700	475
30	543	787	632	855	754
35	638	977	919	971	1004

APPENDIX TABLE F

Heat Flow through Excised Pelt Section

Fleece #2 (Fig. 1F)

Wind Speed (mph)	Temperature (C) +2	-7	-12	-18	-23
0	52	57	49	62	54
5	109	138	141	95	95
10	174	236	252	263	217
15	225	312	331	334	304
25	350	385	472	440	399
30	491	551	611	570	722
35	597	630	733	965	990

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by

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ABSTRACT

Wind Chill Effect for Cattle and Sheep

by Larry W. Insley

The combined effect of wind and temperature during cold was studied using a model in which heat flow through cattle and sheep hides (including hair and wool) was measured. Two hundred ten observations at combinations of temperatures ranging from $-24^{\circ}C$ to $2^{\circ}C$ and wind velocities from 0 to 35 mph were made on two sheep pelts and four cattle hides. Heat loss was plotted for each temperature as a function of wind velocity. In all cases heat flow increased with either decreased temperature or increased wind velocity. When heat flow through hides and pelts was plotted as a function of wind velocity a cubic relationship was found which was significantly (P .01) different than the quadratic function assumed by the U.S. Army wind chill factor for bare flesh. It is hypothesized that increased heat flow at low wind velocities (less than 25 mph) results from decreased insulation of the air interface much like the quadratic relationship of the U.S. Army's wind chill factor. As wind velocity increases above 25 mph, the structure of the external insulation (hair or wool) is destroyed resulting in a second

increase in heat flow. Existing wind chill factors for bare-skinned animals are not applicable to livestock with hair or wool.