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Some Aspects of Solar Radiation in its Relation to Cattle in South Africa and Europe.

By GERTRUD RIEMERSCHMID, Department of Public Health, Pretoria, temporarily attached to Onderstepoort.

THE pioneer work of Dorno has brought to the frontline the necessity of close combination of two branches of science, namely biology and climatology (Dorno, 1911 and later publications). Dorno also was the first to stress the importance of solar radiation with regard to biological research. He included measurements of the intensity and quality of the solar radiation in the collection of climatological data, particularly for the study of the influence of solar radiation on human beings. Later on botanists realized the importance of solar radiation and extended their studies to this subject. With regard to animals, however, very little attention has been paid to solar radiation and an attempt is made in this article to apply data collected by the South African Solar Radiation Survey to cattle living in the open. For a comparison European conditions are also discussed.

The direct effect of solar radiation is twofold: firstly there is the chemical effect of the actinic rays, and secondly the heating effect. The latter only will be discussed in this article.

In order to determine the heating effect on the body surface of cattle, it is essential to know two things: (*a*) the amount of radiation impinging, and (*b*) the physical changes which this radiation will undergo when it strikes the animal. Accordingly this article will be divided into two parts:—

Part I.—The solar radiation and the factors influencing its intensity and total amount in various places.

Part II.—The amount of radiation absorbed on the body surface of cattle in South Africa and Europe.

In Part I the various factors influencing the amount of radiation obtained at various places will be discussed under the following headings:—

1. The altitude of the sun in South Africa and Europe.
2. The midday intensities of the direct solar radiation.
3. The length of the days.
4. The number of hours with bright sunshine.
5. The total amount of sun and sky radiation impinging during various months in South Africa and Europe.

In addition air temperatures will briefly be discussed.

In Part II the absorption of radiation on the body surface of cattle irradiated under South African and European conditions will be discussed under the following headings:—

1. The amount of direct solar radiation.
2. The amount of scattered radiation from the sky.
3. The amount of radiation reflected from the ground.
4. The area of the body surface which is influenced by the various kinds of radiation mentioned under No. 1-3.
6. The total amount of radiation which is absorbed on the body surface of cattle under South African and European conditions.
7. The reduction of the amount of solar radiation by natural and artificial shade.

PART I.

THE SOLAR RADIATION AND THE FACTORS INFLUENCING ITS INTENSITY AND TOTAL AMOUNT IN VARIOUS PLACES.

During the period July, 1937, until June, 1938, a Solar Radiation Survey was carried out in the course of which the intensity of sun and sky radiation was recorded at six places in the Union of South Africa. (Riemerschmid, 1940). These observations were again continued in January, 1940, first at two and subsequently at four stations (Riemerschmid, 1940-41).

The geographical positions of the stations under consideration are mentioned in the appended table.

	Longitude.	*Latitude.*	*Altitude.*
1. *Inland*—			
(*a*) Johannesburg	28° 04′ E.	26° 12′ S.	5,800 ft.
(*b*) Bloemfontein	26° 13′ E.	29° 06′ S.	4,500 ft.
(*c*) Onderstepoort	28° 11′ E.	25° 38′ S.	4,000 ft.
(*d*) Armoedsvlakte	24° 39′ E.	26° 56′ S.	4,080 ft.
2. *Southern Cape*—			
(*a*) Cape Town	18° 28′ E.	33° 56′ S.	40 ft.
(*b*) Stellenbosch	18° 59′ E.	33° 50′ S.	464 ft.
(*c*) Port Elizabeth	25° 37′ E.	33° 37′ S.	250 ft.
3. *Durban*	31° 03′ E.	29° 52′ S.	20 ft.
4. *Messina*	30° 03′ E.	22° 20′ S.	1,800 ft.

The following European stations were selected for comparison with the South African stations:—

	Longitude.	*Latitude.*	*Altitude.*
1. Tunbridge Wells, Sussex	0° 16′ E.	51° 08′ N.	351 ft.
2. Aberdeen, Aberdeen	2° 06′ W.	57° 10′ N.	79 ft.
3. Kew Observatory, Richmond, Surrey	0° 19′ W.	51° 28′ N.	47 ft.
4. Davos, Switzerland	9° 49′ E.	46° 48′ N.	5,250 ft.
5. Bad Nauheim, Germany	8° 45′ E.	50° 22′ N.	492 ft.
6. Potsdam, Germany	13° 04′ E.	52° 23′ N.	323 ft.

1. *The altitude of the sun in South Africa and Europe.*

When considering the influence of radiation on any surface it must be realized that the angle of incidence influences the effect on the irradiated surface. Applying this to solar radiation as obtained in various parts of the globe, the altitude of the sun plays an important rôle.

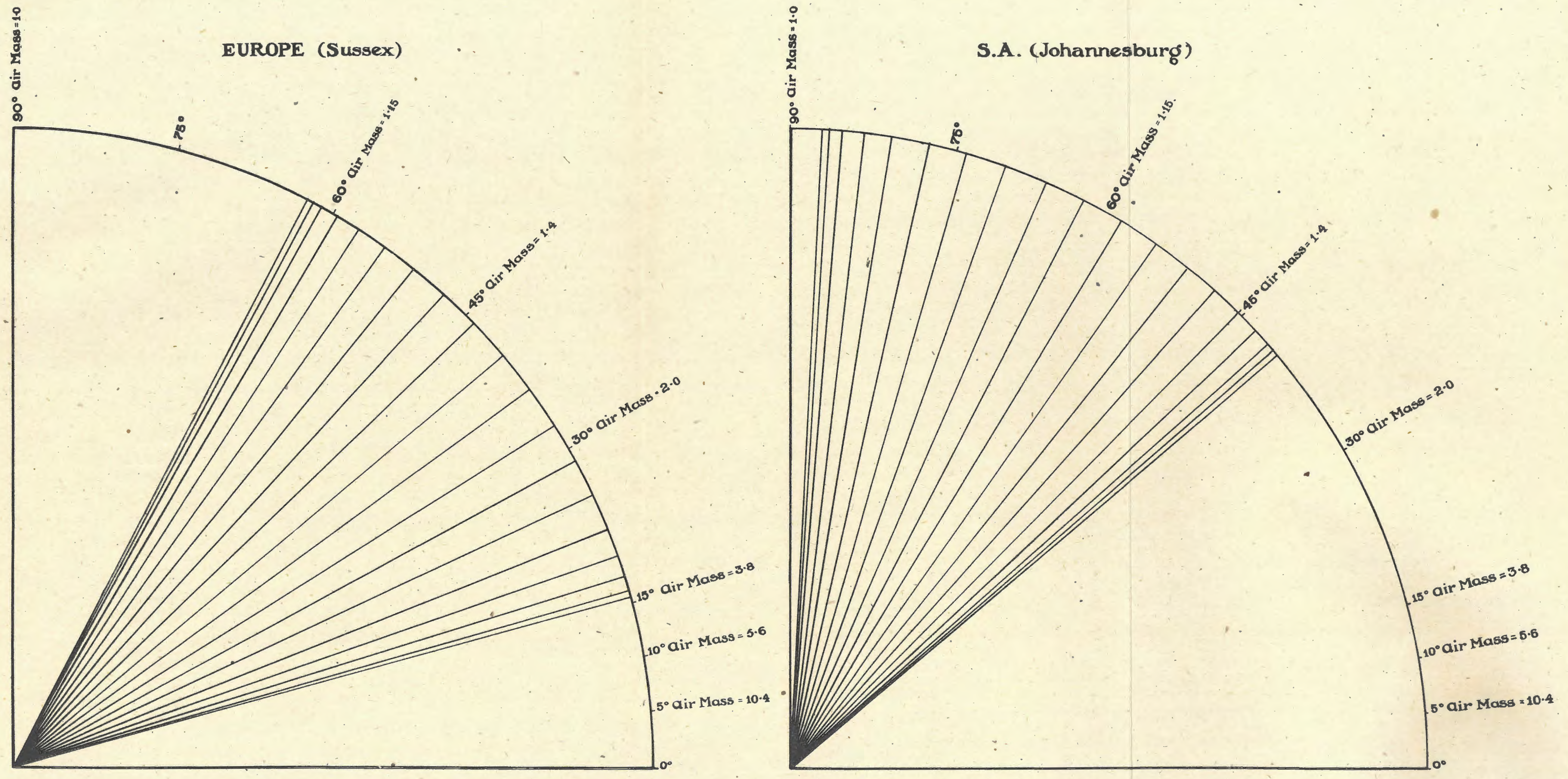

Fig. 1. Incidence of solar rays at midday in S.A. and Europe.

Note: Each slanting line represents approximately 20 days.

A demonstration of the altitude of the sun at various places seems rather difficult because it alters continuously. Each day, however, the sun reaches its maximum height (culmination) at noon solar time and the angle of culmination gives some indication of the sun heights prevailing during a large part of any day. In Fig. 1 an attempt is made to represent the culmination points of the sun graphically. In the figure each line radiating from the origin of the graph represents 20 days and the scale on the arc gives the mean altitude of culmination during these twenty days. In Sussex, for instance, the mid-winter culmination is 15°, whilst at the inland stations in South Africa the mid-winter culmination is 39°. The respective figures for mid-summer are 62° for Sussex and 87° for South Africa.

Conclusion.—The sector from which the solar rays are striking on a horizontal surface during the hours round about midday is much closer to the horizon in Europe than in South Africa. Consequently the layer of air (at equal altitudes above sea-level) between the sun and the observation station is thicker in Europe than in South Africa.

2. *Midday intensities of the direct solar radiation in South Africa and Europe.*

There are two recognised ways of measuring the intensity of the sun's energy reaching the surface of the earth. One method is to measure the solar radiation alone with an instrument which is shielded against the sky radiation. In this case the measuring surface of the instrument is, for each observation, adjusted perpendicularly to the solar beam. The other method is the measurement of the total amount of sun *and* sky radiation incident on a horizontal surface.

The midday intensities were obtained by applying the first method, i.e. by measuring the intensity at a right angle to the solar beam. Data so obtained are strictly comparative because the angle of incidence on the receiving surface is always the same. Differences in the readings are therefore due to the atmospheric conditions and their reducing effect only. The figures are significant for the transmission of the atmosphere; for biological considerations, however, sky and reflected radiation have to be included.

TABLE 1.—*Midday intensities of the direct solar radiation at various places in the Union and in Europe.*

	Durban.	Kew.		Davos.	Johannesburg.	
January...........	1·42	1·23	July	1·46	1·58	January.
February...........	1·39	1·22	August	1·46	1·56	February.
March.............	1·36	1·18	September	1·46	1·52	March.
April..............	1·32	1·09	October	1·45	1·47	April.
May...............	1·29	0·95	November	1·41	1·41	May.
June..............	1·25	0·86	December	1·36	1·38	June.
July...............	1·27	0·88	January	1·39	1·39	July.
August............	1·32	0·99	February	1·48	1·43	August.
September.........	1·36	1·32	March	1·52	1·50	September.
October............	1·39	1·21	April	1·51	1·55	October.
November.........	1·41	1·23	May	1·47	1·59	November.
December..........	1·43	1·23	June	1·46	1·59	December.
MEAN.............	1·35	1·10		1·44	1·50	MEAN.

Table 1 gives the midday intensities in gram calories per square centimetre per minute for Johannesburg (Riemerschmid, 1940) (5,800 feet above sea-level) and Davos (Lindholm, 1929) (5,250 ft.) and for Durban (Riemerschmid, 1940) (sea-level) and Kew, Surrey (Observatories Year Book, 1911-21) (47 ft.). The data given in the table were obtained from readings taken on clear days within half an hour of midday. From these data graphs showing the mean annual variation of the midday intensities were drawn up and the values for the middle of each month were read from this graph. The data are given for the corresponding months of the Southern and Northern hemisphere, namely January as compared with July (mid-summer of both hemispheres), February and August, etc.

At *low altitudes* above sea-level, namely at Durban and Kew, the comparison shows a considerable difference between the midday intensities. This difference is greatest in mid-winter, when Kew shows intensities which are up to 31 per cent. smaller than those measured at Durban. In summer the difference is still considerable; the midday intensities at Durban are approximately 13 per cent. higher than at Kew.

At *high altitudes* above sea-level (Johannesburg and Davos) the comparison shows a very small difference, amounting to 8 per cent. at the utmost, but being only 4 per cent. on an average.

Conclusion: The fact that the difference of midday intensities at stations in Europe and South Africa does not exceed 31 per cent. at low altitudes above sea-level and is not greater than 4-8 per cent. at high altitudes must be strongly emphasized. It proves that the general conception of the intensities of the solar radiation in South Africa is, unfortunately, quite wrong in that it implies that the radiation as such is many times as intense as it is in Europe.

3. *The length of the days in South Africa and Europe.*

The length of the days in mid-winter and mid-summer for some representative places in South Africa and Europe are presented in Fig. 2. The following places were selected for this comparison: Johannesburg and Capetown, and Davos and Sussex. The time between sunrise and sunset is represented by the respective lengths of the blocks in Fig. 2. The length of the days at the other South African stations (except Messina) is intermediate between Johannesburg and Cape Town; in the same way the length of the days in Bad Nauheim is intermediate between the two European examples given in Fig. 2.

Conclusion: Fig. 2 shows that in summer the days are shorter in South Africa than in Europe, whereas the opposite holds in winter. It also shows that the difference between the length of the South African summer and winter day is smaller than the difference between the summer and winter day in Europe.

4. *Number of hours with bright sunshine in South Africa and Europe.*

One of the most important factors influencing the amount of radiation obtained in various places is the cloudiness. Table 2 gives a comparison of the number of hours of bright sunshine for various places in the Union, in Switzerland, in Germany and in the home counties of two of the cattle breeds imported into South Africa, Sussex and Aberdeen.

TABLE 2.—*Number of bright sunshine hours in South Africa and Europe.*

	EUROPE.				SOUTH AFRICA.			
	Aberdeen and Perth. (Mean Value).	Tunbridge Wells.	Davos.	Bad Nauheim	Inland.	Cape.	Durban.	
April.........	4·8	5·2	4·8	4·9	9·4	8·5	4·8	October.
May..........	5·5	6·9	5·9	6·7	9·7	9·3	4·5	November.
June.........	6·3	7·1	5·7	6·7	9·8	10·2	4·7	December.
July...........	5·3	6·8	6·4	6·4	8·9	9·7	5·4	January.
August.......	4·6	6·4	6·6	5·8	8·8	8·6	5·9	February.
September....	4·2	5·4	5·5	4·1	8·6	8·1	6·1	March.
October.......	2·9	3·6	4·4	2·7	8·8	7·2	6·5	April.
November....	1·9	2·2	3·2	1·3	8·7	6·5	6·5	May.
December.....	1·1	1·4	2·4	0·7	8·7	6·6	6·6	June.
January......	1·45	1·7	2·7	1·4	8·8	6·5	6·3	July.
February.....	2·4	2·7	4·1	2·2	9·5	6·9	6·3	August.
March........	3·5	4·0	4·7	3·0	9·3	7·0	5·6	September.
MEAN.........	3·7	4·5	4·5	3·8	9·1	7·9	5·8	MEAN.

The figures in Table 2 are very striking, because they show a very marked difference between the conditions in South Africa and Europe; the figures speak for themselves. They partly give the explanation why the *total* amount of solar energy can be much greater in some parts of South Africa than in Europe.

Conclusion: The European stations show little over four hours of bright sunshine on an average, in some South African localities the amount is twice as great.

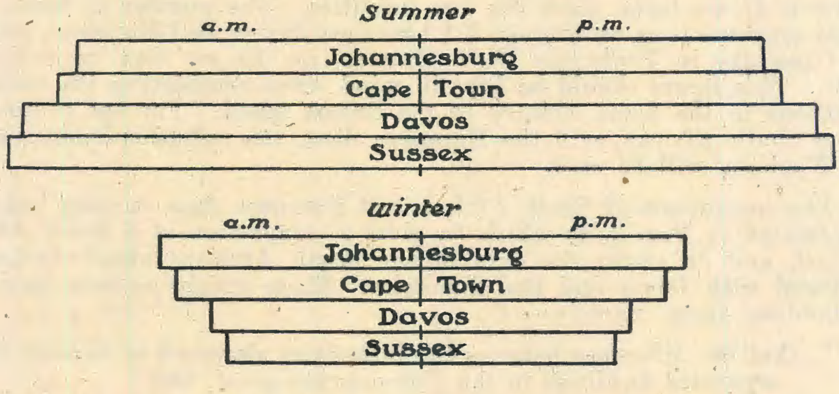

Fig. 2. Length of Days in S.A. and Europe.

5. *Total amount of sun and sky radiation impinging during various months in South Africa and in Europe.*

Until now intensities have been considered which were measured perpendicular to the incidence of the rays. In the following paragraph the total radiation incident on a *horizontal* surface, including sky radiation, will be discussed. The figures are given in *Kilogram* calories (Cals) per square centimetre.

The South African readings which were obtained at various stations and during different years were combined and mean values for the following groups are given:—

1. Inland stations, including results from Johannesburg (1 year), Bloemfontein (1 year), Onderstepoort (2 years), Armoedsvlakte (2 years).
2. Southern Cape, including results from Cape Town (1 year), Stellenbosch (1 year), Port Elizabeth (1 year).
3. Durban (1 year).
4. Messina (1 year).

The deviation from the mean values given below were not more than 5 per cent. from the average at the inland stations for the summer or winter half year, but amounted usually up to 20 per cent. in a single month and in two cases even up to 27 and 30 per cent. In the Cape the means deviated by 6 per cent. from the summer and winter means; during single months the deviation was nearly the same as at the inland stations.

Continuous records of the total amount of sun and sky radiation impinging on a horizontal surface have, unfortunately, never been published for any place in the British Isles. It is therefore necessary to consider whether an approximate estimate can be obtained from readings recorded elsewhere. For this purpose data published for Bad Nauheim seem most suitable for the following reasons: The centre of the area for Sussex cattle lies at about the same latitude as Bad Nauheim (51°08'N and 50°22'N respectively) giving practically the same angle of incidence of the rays on a horizontal surface in both places. Furthermore, both places are situated at about the same altitude above sea-level, which means an approximately equal thickness of air layer above the two localities. The number of hours with bright sunshine is on an average 3·8 hours per day in Bad Nauheim, and 4·5 hours per day in Tunbridge Wells, Sussex, i.e. 15 per cent. more for the latter. This figure should be kept in mind when considering the radiation conditions in the home country of the Sussex breed. For the comparison of the South African with the European data, the radiation intensities for Bad Nauheim will be used.

The comparison of South African and European data on solar radiation is presented in Fig. 3, in which 3a gives a comparison of 4 South African stations, and 3b shows the data of the South African inland stations as compared with Davos and Bad Nauheim. These graphs at once show two outstanding facts, namely—

1. that the difference between the intensities measured at various widely separated localities in the Union is not great, and
2. that a comparison with European conditions shows a marked drop of itensities during the winter months in Europe, which is not so pronounced in the Union of South Africa.

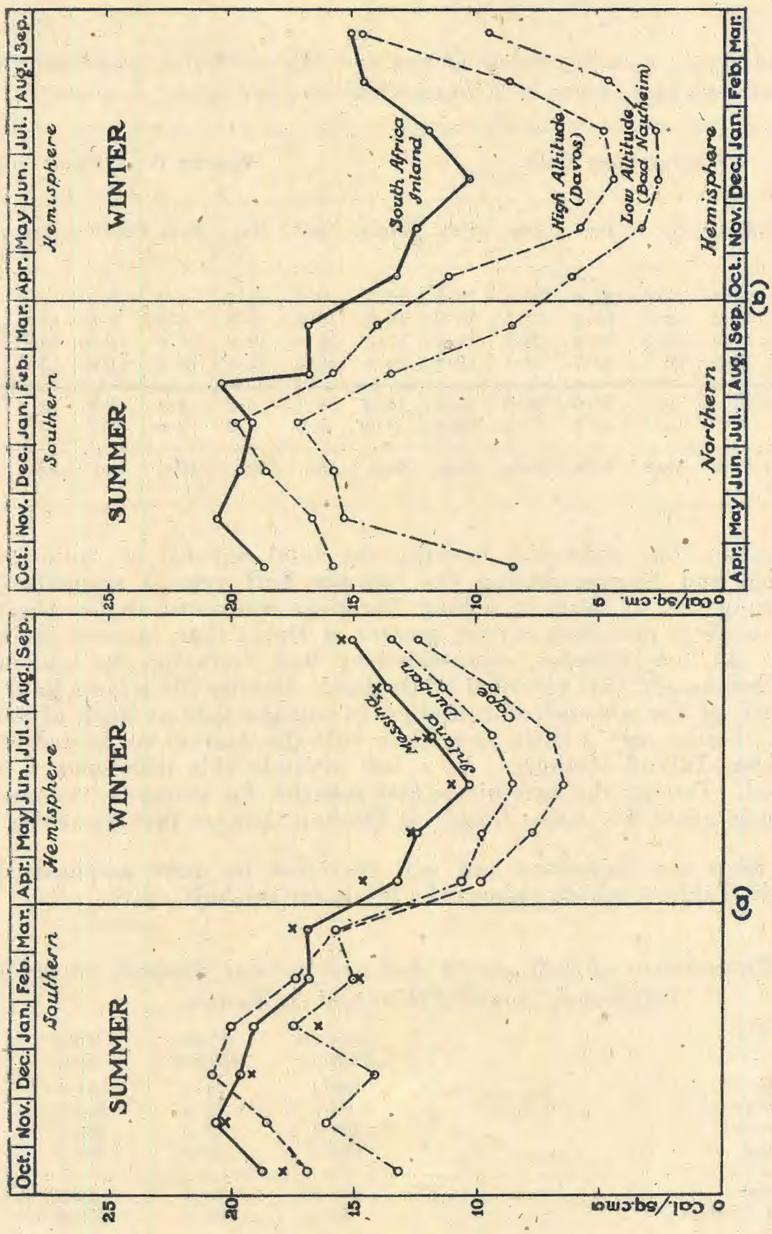

Fig. 3: Monthly total amounts of sun and sky radiation.
(a) at various stations in South Africa.
(b) at 2 stations in Europe as compared with South African inland stations.

A much closer study of the conditions is facilitated by the figures in Table 3, which gives the monthly totals obtained by the Solar Radiation Survey in the Union and the corresponding data for Davos and Bad Nauheim.

TABLE 3.—*Average monthly totals of sun and sky radiation, impinging on a horizontal surface, given in Kilogram calories per square centimetre.*

	SUMMER HALF YEAR.						WINTER HALF YEAR.					
Month.......	Oct.	Nov.	Dec.	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.
Cape........	16·9	18·6	20·8	20·0	17·3	15·7	9·8	7·7	6·4	6·9	9·3	12·3
Durban......	13·2	16·2	14·2	17·5	15·0	15·7	10·6	9·8	8·6	9·3	11·3	13·4
Messina......	17·9	20·3	19·2	16·5	14·8	17·5	14·6	12·6	11·0	11·9	14·0	15·5
Inland.......	18·7	20·5	19·7	19·1	16·8	16·8	13·2	12·4	10·2	11·8	13·6	15·0
Davos.......	15·8	16·7	18·6	19·8	15·8	14·0	11·1	5·7	4·4	4·8	8·6	14·6
Bad. Nauheim	8·5	15·4	15·8	17·2	13·4	8·6	6·0	2·2	1·6	1·7	3·6	9·4
Month.......	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.

Conclusion: The difference between the total amount of radiation in South Africa and Europe during the *summer* half year is comparatively small. During the 16 hours of a long European mid-summer day the total amount of incident radiation is even greater at Davos than in most places in the Union. At low altitudes, represented by Bad Nauheim, the amount of energy reaches nearly that recorded at Durban. During the *winter* half year the difference of the amount of radiation is considerable at high altitudes. Davos then obtains only a little more than half the amount registered at the South African Inland stations. At a low altitude this difference is even more marked. During the two mid-winter months, for instance, the amount of radiation is about five times bigger at Durban than at Bad Nauheim.

These facts are important and will therefore be more emphasized by the figures in Table 4, which present the totals for the half years.

TABLE 4.—*Comparison of half yearly and yearly total amounts of radiation incident in South Africa and in Europe.*

	Summer Halfyear.	*Winter Halfyear.*	*Total Year.*
Cape..................................	109·4	52·4	161·8
Durban................................	91·8	63·0	154·8
Messina...............................	106·2	79·6	185·8
Inland................................	111·5	75·8	187·3
Davos.................................	100·9	49·2	150·1
Bad Nauheim...........................	78·9	24·5	103·4

The figures in Table 4 show that during the summer half year at Bad Nauheim 79 Cals (or 70 per cent.) were recorded, as compared with 112 Cals (100 per cent.) recorded at the South African inland stations. In winter this difference is much bigger, Bad Nauheim recording only ·32 per cent. of the amount registered at the South African inland stations. The totals for the year show 103 Cals. at the former, and 187 Cals. at the latter station.

This clearly demonstrates that *the differences in the annual totals are due predominantly to the differences during the winter half year* and less so to those during the summer half year. If this is so, the question might be asked whether the much greater total annual amount of radiation is really of such significance? If it were proved that too much solar radiation had a harmful influence on cattle, would not everybody expect this influence to take place particularly during the hot summer months rather than during the cooler winter, when the solar radiation is a pleasantly warming factor.

Summarizing, the comparison between the South African and European stations shows the following:—

1. *Angle of incidence of the solar rays.* Distinctly larger in South Africa.
2. *Midday intensities.* At Johannesburg nearly equal to those at Davos, but at Durban on an average higher than at Kew.
3. *Length of days.* Days in South Africa shorter during the summer, but longer during winter than in Europe.
4. *Number of hours with bright sunshine.* South Africa many more hours with bright sunshine during the whole year, but particularly during winter.
5. *Monthly total amount of sun and sky radiation incident on horizontal surface.* In summer equal or slightly greater amounts in South Africa, in winter amounts much larger here than at the European stations.
6. *Yearly total.* Much greater amount at the South African inland stations (187 Cals/cm^2) than at the lowlands of Europe (103 Cal/cm^2).

Before we turn to the discussion of how much solar radiation is incident on the surface of cattle in South Africa and Europe it seems desirable to point out the possibility that two factors may cause a stronger influence of the radiation here than in Europe:—

1. The exposure to comparatively great amounts of radiation *throughout the year.*
2. The simultaneous influence of other climatic factors, such as air temperature, humidity and wind.

These three latter factors play an important rôle with regard to the possibility of losing heat against the environment (see page 350). A discussion on this point does not lie within the scope of this article, but it is of interest to give an indication of the conditions prevailing in South Africa and Europe. The cooling effect of the air depends largely on its movement, because in absolute calmness this effect is comparatively small. In the open, however, the air is seldom absolutely calm; its temperature is then one of the factors governing its cooling effect. The difference between normal body temperature (102° F.) and the maximum average air temperature for various localities in South Africa and Europe is presented in Table 5.

TABLE 5.

Difference between body (102° *F.*) *and maximum air temperature* (*in degrees F.*).

Stations.	SUMMER.						WINTER.						Yr.
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	
Cape Town	31	28	24	**22**	**22**	24	28	33	**36**	**37**	**36**	35	30
Durban	27	25	23	**21**	**21**	23	24	27	30	**31**	**31**	30	26
Messina	13	12	**11**	**11**	13	14	17	21	**25**	**27**	23	18	17
Inland	20	20	**17**	**17**	19	22	26	32	**37**	**37**	32	26	25
Kew	49	42	37	**33**	**33**	37	45	53	56	**57**	**57**	54	46
Aberdeen	54	49	43	**40**	**40**	44	50	56	**59**	**59**	**59**	57	51
Davos	46	38	31	**28**	**30**	35	41	52	**61**	**62**	60	54	45
	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Yr.

NOTE.—The bold figures indicate the two months during which the difference between maximum air temperature and body temperature is smallest in summer and largest in winter.

Conclusion.—During the two *hottest* months of the year the average maximum air temperature at the South African stations is 11 to 23° F., at the European stations 33 to 44° F. below normal body temperature of cattle. During the *coldest* months of the year the difference between average maximum air temperature and body temperature is 25 to 37° F. at the South African, and 57 to 59° F. at the European stations.

PART II.

THE AMOUNT OF RADIATION ABSORBED ON THE BODY SURFACE OF CATTLE IN SOUTH AFRICA AND EUROPE.

The factors which determine the amount of radiation absorbed by the body surface of cattle change continually, from hour to hour as well as from day to day. Firstly there is the intensity of the incident radiation which depends largely on the amount of clouds present, and which varies with the altitude of the sun, with the thickness of the air layer and its composition. Secondly, with a given intensity of the solar beam, the amount which is actually absorbed depends on the colour and the nature of the surface of the animal, as well as on its size. Lastly, there is the animal itself which continually changes its position and by doing so exposes its side or its front to the incoming beam of solar radiation. The large number of variables make a calculation of their combined effect very involved and it is consequently essential to restrict our discussion to a few clearly defined examples.

This discussion will be confined to clear days only because they represent extreme conditions of insolation. Mid-summer and mid-winter readings are selected to represent the highest possible amount of radiation incident during a clear, long mid-summer day and a short mid-winter day, with high and low sun altitudes respectively. With regard to the colour of the hides, the discussion is limited to brown hides only, since brown is one of the most common colours of cattle in South Africa. Preliminary measurements on hides of different colours have shown that the absorption varies a great deal, and detailed investigations on this subject are still in progress. With regard to the posture of the animal two extreme cases are considered, firstly when the animal is kept at right angles to the sun's rays, and secondly when it is facing the sun. These two cases represent conditions under which the animal is exposed to the smallest and largest possible amount of radiation respectively. In any other position the animal must obtain an amount which lies between these two extremes.

To repeat: The following discussion will include clear days only, in mid-summer and mid-winter, the solar rays striking the animal perpendicularly or parallel to its sagittal axis. *It is realized that, although the calculations are based on accurately determined figures, the combination of them can only give an approximate estimate of the true conditions.*

The *total amount of radiation* which is absorbed by the hairy coat of cattle depends firstly on the amount of incoming radiation and secondly on how much of this incoming radiation is absorbed.

The incoming radiation consists of—

(*a*) the amount of direct solar radiation;

(*b*) the amount of scattered radiation from the sky;

(*c*) the amount of radiation reflected from the ground.

How much of the incoming radiation is absorbed depends on the following factors:—

(*a*) the size of the animal, which determines the area exposed to radiation; the amount absorbed is determined by the cross section which the animal presents to the incoming *direct* solar radiation, and by the total curved area for *sky* radiation and radiation *reflected from the ground*;

(*b*) the absorption coefficient of the hairy coat, i.e., the percentage of the incident radiation which is absorbed. This absorption coefficient varies with the angle of incidence of the rays on the various parts of the body.

Before one can discuss the combined influences of all these factors, it is again essential, as in Part I of this paper, to deal with the various factors separately.

The stations under consideration in this comparison are Johannesburg (S.A.), Davos (Switzerland) and Potsdam (Germany). The latter station will replace Bad Nauheim in the following discussion, because data for Bad Nauheim suitable for a comparison, are not available and Potsdam represents approximately similar conditions. (For geographic data of the above-mentioned places see page 328.

1. *The amount of direct solar radiation.*

Table 6 gives mean values of the direct solar radiation (measured perpendicularly to the solar beam) for clear days, related to the sun's altitude.

TABLE 6.

Intensity of direct solar radiation on clear days in mid-summer and mid-winter related to sun heights in gram calories per square centimetre per minute (from "Tabellen, etc.", 1938).

	MID-SUMMER.									
Sun's altitude	5°	10°	15°	20°	30°	40°	50°	60°	70°	80°
Johannesburg	0·52	0·83	1·01	1·14	1·33	1·44	1·51	1·55	1·56	1·58
Davos	—	—	—	0·89	1·25	1·33	1·38	1·42	—	—
Potsdam	0·27	0·53	0·73	0·85	1·03	1·14	1·21	1·26	—	—
	MID-WINTER.									
Sun's altitude	5°	10°	15°	20°	30°	40°	50°	60°	70°	80°
Johannesburg	0·35	0·60	0·81	0·98	1·22	1·35	—	—	—	—
Davos	—	1·07	1·26	1·37	—	—	—	—	—	—
Potsdam	0·52	0·82	1·00	—	—	—	—	—	—	—

2. *The amount of scattered radiation from the sky.*

This was frequently measured during the period when the South African Solar Radiation Survey was carried out. The ratio between sun and sky radiation (total per day) was found to be approximately 11 : 1 on clear summer days and 8 : 1 on clear winter days. An average ratio of 10 : 1 was used for the Johannesburg calculations. For Europe very few data are available. From readings published by Dorno (1927) it seems justified to assume an average ratio of 10 : 1 for Davos and of 4 : 1 for Potsdam.

3. *The amount of radiation reflected from the ground.*

Of the total amount of radiation incident on a horizontal surface on a cloudless day a certain amount is reflected from the ground. This amount depends on the nature of the surface of the ground. Measurements carried out at Onderstepoort at a sun's altitude of about 30° showed readings similar to those published by various authors (see Büttner, 1938), namely:—

> The reflection from a surface of green short grass was found to be 30 per cent. of the total incoming radiation.
>
> The reflection from light brown dry grass amounted to 28 per cent., and the reflection from a greyish sandy road was 26 per cent.

For the following calculation a mean value of 30 per cent. reflection of the total incoming radiation by the ground was assumed.

4. *The body surface area and how much of it is influenced by the direct solar, the sky radiation and the radiation reflected from the ground.*

(*a*) *The body surface area and direct solar radiation.*

The amount of direct radiation incident on the animal at various sun heights can be estimated by multiplying the area of the shadow which it casts on a horizontal surface by the intensity of the direct radiation, also measured on a horizontal surface.

The size of the shadow of the animal varies with the height of the sun and had, therefore, to be determined at various altitudes of the sun. The animal used was a full grown Sussex bull, 3 years old, 1,760 lb. in weight. The shadow areas are given in the form of a graph in Fig. 4. The abscissa represents the sun altitudes at which drawings of the bull's shadow were made, the ordinate indicates the size of the shadow in square centimetres. The shadows were measured on a horizontal plane except for sun altitudes lower than 15° for which the projection on a vertical plane was used. Graph A in Fig. 4 represents the bull standing perpendicularly to the direction of the sun's beam, graph B shows the shadow areas when the bull was facing the sun, i.e., the greatest and smallest possible shadow area at each particular sun altitude.

(*b*) *The body surface area influenced by the sky radiation.*

The total surface area of the bull was obtained from measurements of hides from 3 bulls similar in size and weight to the one which was used for the determination of shadow areas.* The average total surface area was 75 square feet or 65,000 square centimetres. This figure was verified by applying Hogan's (1923) formula to the bull used in this experiment. The surface area calculated is 64,500 sq. cm. The measured value of 65,000 sq. cm. was used. The contribution of the sky radiation should be halved because the animal is not completely surrounded by sky but receives sky radiation from above only. This amounts to the same as using half the surface area of the bull for the calculation of the sky radiation and half the area for the radiation reflected from the ground. For the calculation of the sky radiation, therefore, half the total surface area or 32,500 sq. cm. were used.

(*c*) *The body surface area influenced by the radiation reflected from the ground.*

The same considerations as mentioned under (*b*) refer to the radiation reflected from the ground on to the animal, the area being also approximately 32,500 square centimetres.

5. *The absorption of the radiation by the hairy coat of brown cattle.*

(*a*) *The absorption of direct solar radiation.*

The absorption of direct solar radiation on the hairy coat of cattle was determined by measuring the amount of radiation reflected from hides. The use of hides was necessary, because a living animal is not large enough to cover the whole area from which the instrument receives radiation. The measurements had, therefore, to be carried out on hides spread out level on a large board. In order to ascertain whether one is entitled to apply readings obtained from a dead hide to a living animal the following experiment was carried out:—

On a cloudless day the bull was placed in a crush so that he could not alter his position with regard to the incoming rays or to the background before which he was standing. Within a few minutes (practically no change in intensity or direction of the sun's rays having taken place) the total incoming radiation and the radiation reflected from the bull was measured.

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* These measurements were kindly placed at my disposal by Prof. J. H. R. Bisschop.

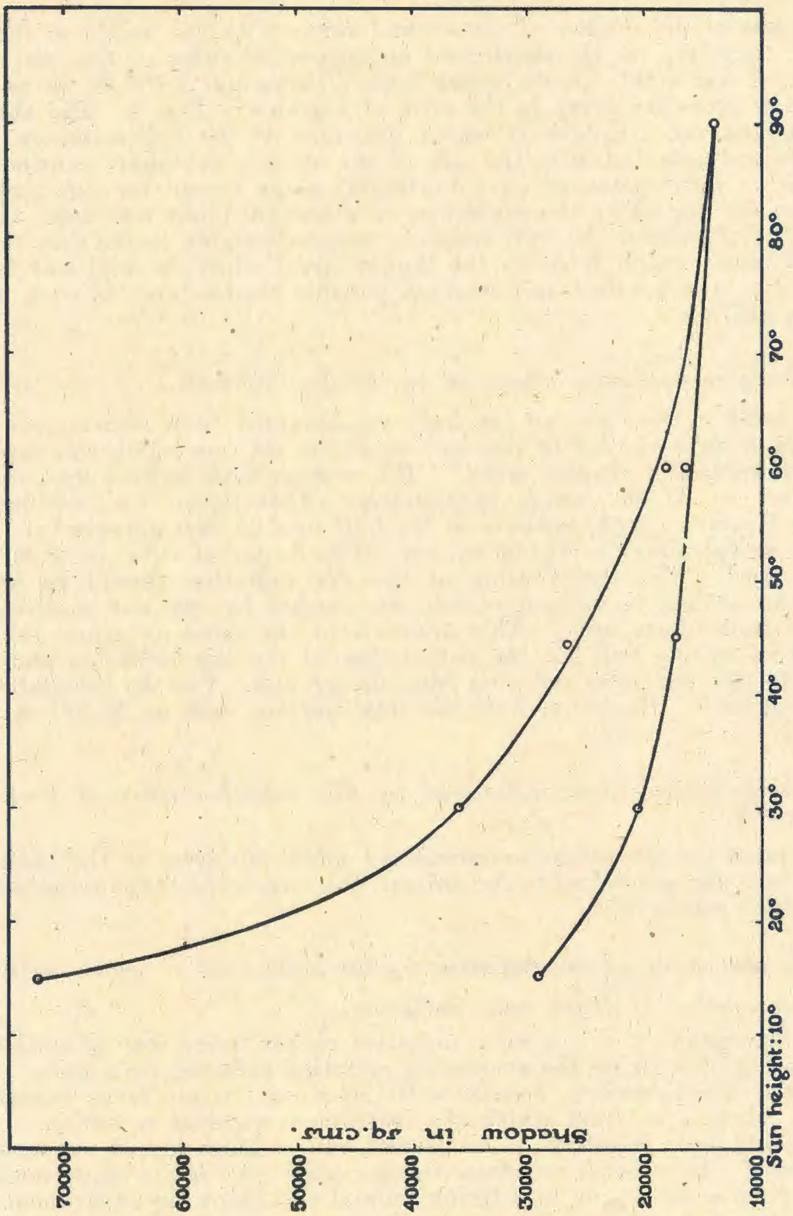

Fig. 4: Size of shadow of a bull measured at various altitudes of the sun

Immediately afterwards the bull was covered with a dead hide, which was tied round his body so that the surface presented the same shape as the animal's body. The incoming and reflected radiation were then again determined. The results obtained were the following:—

	Absorption.				
Sussex bull, dark brown	81%	87%	80%	80%	87%
Sussex hide, dark brown	79%	87%	—	—	—
Red Poll hide, lighter brown ...	—	—	79%	78%	86%

These readings are not absolute, but only relative values which permit us to compare results obtained from a living animal and a dead hide. The readings show that the absorption in both is equal (within the limit of the instrumental error). This proves:—

1. That the absorption on the hairy coat of cattle does *not* depend on the state of the underlying skin.
2. That the absorption is determined only by the absorbing power of the hairy coat.
3. That the difference in the hairy coat of a living animal or a dead hide (with regard to dustiness, smoothness and glossiness) results in minute differences in absorption if the colour in both cases is similar.

To determine whether a change in functional activity of a living animal results in a difference between animal and hide readings, measurements were carried out on the bull after he had a hard fight with another bull. He was panting heavily (at a low air temperature) which shows that he was on a higher level of functional activity than usually. The absorption was found to be equal, i.e. 87 per cent. on the bull and on the hide.

The reflection from cattle hides was determined with a thermopile at various angles of incidence of the solar beam. Owing to the fact that the reflecting power of a surface depends on its colour and the structure of its surface, it can be assumed that different hides might show different absorption coefficients. The present investigation was restricted to one example, namely the absorption on brown hides of different structure. A hide of a Sussex × Afrikaner ox and another one from a high grade Afrikaner cow were used. The colour of the two hides was similar, the structure of the hairy coat distinctly smoother and the hairs more glossy in the case of the high-grade Afrikaner. The Sussex × Afrikaner hide had been dried, the other hide was used immediately after slaughtering without being washed or dried to represent as closely as possible the hide of a living animal.

The influence of the direction of the hair on the absorption of the incident rays was also taken into consideration. Reflection readings were taken when the hairs were pointing towards the sun (or to be more precise in the azimuthal plane of the sun), away from the sun or at right angles to the incoming rays. The absorption coefficients obtained from these measurements are given in Fig. 5, where the circles refer to the Sussex × Afrikaner hide, the dots to the high-grade Afrikaner hide.

Conclusion.—As will be seen from the graph in Fig. 5 there is only a small difference in absorption between the Afrikaner × Sussex hide and the high-grade Afrikaner hide. The absorption on the high grade Afrikaner hide is only about 2-4 per cent. less, due to the difference in structure, glossiness and colour. The direction of the hairs with regard to the incoming rays results in a very small difference of absorption at great altitudes of the sun. Only at low solar altitudes is the absorption distinctly higher when the hairs are pointing towards the sun. Below an altitude of 30° the absorption decreases more rapidly, but nevertheless at 10° it still amounts to 50 per cent., whether the hair is pointing towards or away from the sun.

An average absorption coefficient was estimated by calculating the contribution which various areas corresponding to different angles of incidence make to the total absorption. To facilitate the estimation of this contribution the bull was regarded firstly as a right circular cylinder (for the beef type of cattle) and secondly as a cylinder of elliptical cross section (milk type), the height of the ellipse being one and a half times its width. The figures representing the contributions of the various areas were multiplied by the corresponding absorption coefficients and a weighted average was so obtained. The values were: for the circular section 80 per cent., and for the elliptical section 78 per cent. which suggests that the difference in shape of a circular or an elliptical cross section does not greatly influence the mean absorption coefficient. A value of 80 per cent. mean absorption was assumed in the following calculations.

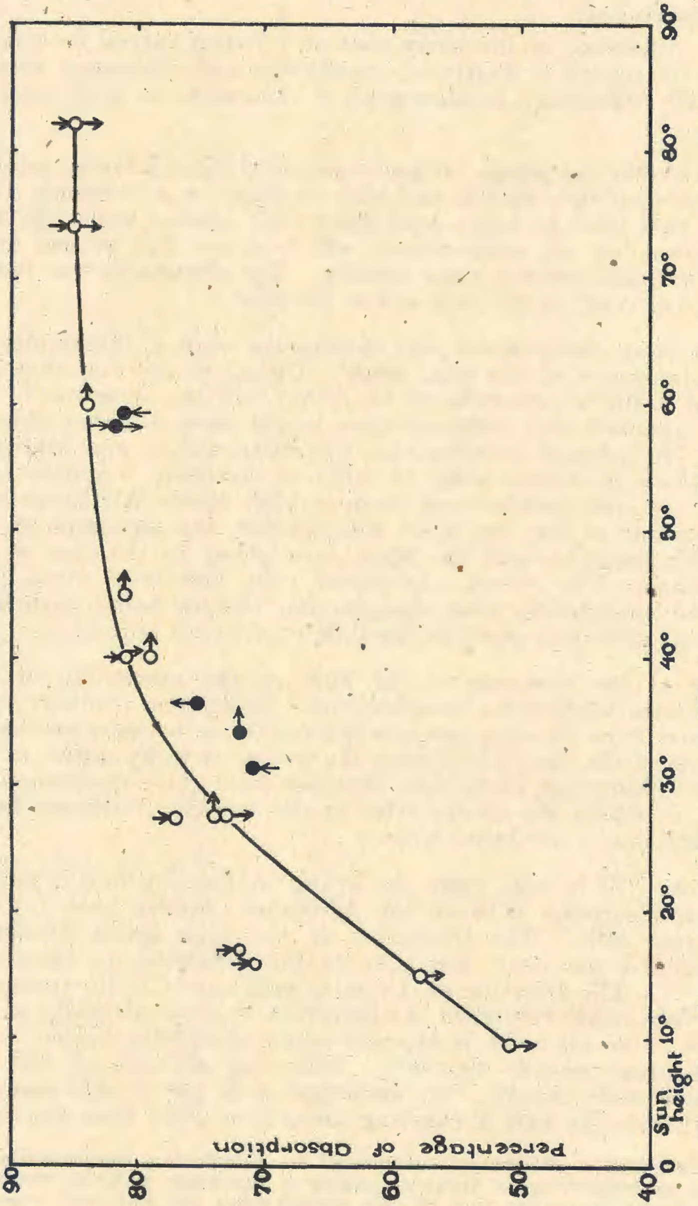

Fig 5: Absorption coefficient of direct solar radiation measured on a hide with hair pointing :—

o↓ - away from sun. ↓o - towards sun. o→ - at angle of 90°.

○ = SussexxAfrikaner ● = High grade Afrikaner (*b*) *The absorption of the sky radiation.*

The reflection of the sky radiation from the horizontally spread hide was determined at various sun altitudes, by measuring the reflection when the hide was shaded against direct solar radiation. The absorption was found to be approximately 72 per cent., irrespective of the altitude of the sun.

(*c*) *The absorption of the radiation reflected from the ground.*

Since the radiation reflected from the ground is similar in composition to the direct solar radiation in that it is composed of all wavelengths, the figure of 80 per cent. reflection is used.

From all the above-mentioned data it is possible to calculate the approximate amount of radiation which is actually absorbed by the surface of cattle under certain conditions. Before this calculation is presented it seems desirable, however, to summarize shortly the various items which have been used for this calculation.

Items:	*Figures used:*
1. The intensity of the direct solar beam.	See Table 6, page 340.
2. The intensity of the scattered radiation from the sky.	1/10 of the direct solar radiation at Johannesburg and Davos, ½ of the solar radiation at Potsdam.
3. The intensity of the radiation reflected from the ground.	This was measured and found to be 30 per cent. of the total sun and sky radiation.
4. The body surface area influenced by direct solar radiation.	The shadow of a bull was measured at various altitudes of the sun, see Fig. 4, page 342.
5. The body surface area influenced by sky radiation.	Half the total surface area, i.e. 32,500 sq. cm. were used.
6. The body surface area influenced by the radiation reflected from the ground.	As under No. 5.
7. Absorption co-efficient of direct solar radiation at various angles of incidence of the rays on brown hides when spread over a level surface.	This was measured on hides of two different breeds of cattle; the results are given in Fig. 5, page 344.
8 Mean absorption coefficient of direct solar radiation considering the contribution of various areas with regard to the angle of incidence on them.	The weighted average of absorption on cattle was estimated to be 80 per cent. of the incoming direct solar radiation.
9. The absorption of sky radiation.	This was measured and found to be approximately 72 per cent. of the incoming sky radiation.
10. The absorption of radiation reflected from the ground.	This was estimated to be 80 per cent. of the radiation reflected from the ground (see under No. 3).

N.B.—It will be remembered that the intensities of cloudless midsummer and cloudless mid-winter days have been used for the calculations and that it was assumed that the animal was either facing the sun (parallel) or standing at a right angle to the incoming solar beam (perpendicular).

TABLE 7.

Calculation of the Total Amount of Direct Solar Radiation Absorbed on the Body Surface of a Bull.

True (Solar) Time.	Sun's Altitude.	Intensity of Direct Solar Radiation. (cals./min.)	Intensity × Sinus Sun Height (*h*).	RIGHT ANGLE.				PARALLEL.			
				Shadow Area in sq. cm.	Shadow Area × Sinus (*h*).	Solar Radiation *Incident* on Body Surface in cals./min.	Solar Radiation *Absorbed.* (80 % of the incident radiation.)	Shadow Area in sq. cm.	Shadow Area × Sinus (*h*).	Solar Radiation *Incident* on Body Surface in cals./min.	Solar Radiation *Absorbed.* (80 % of the incident radiation.)
JOHANNESBURG SUMMER-DAY.											
5·35	5°	0·52	—	—	(19,500)	10,100	8,100	—	—	—	—
5·52	10°	0·83	—	—	(19,100)	15,900	12,700	33,900	5,900	4,900	3,900
6·21	15°	1·01	—	72,400	18,750	18,900	15,100	28,600	7,400	7,500	6,000
6·45	20°	1·14	—	53,300	18,200	20,800	16,600	24,800	8,500	9,700	7,800
7·30	30°	1·33	—	36,300	18,100	24,100	19,300	20,100	10,100	13,400	10,700
8·18	40°	1·44	0·93	28,800	—	26,800	21,400	18,100	—	16,800	13,400
8·40	45°	1·48	1·05	25,900	—	27,200	21,800	17,200	—	18,100	14,500
9·04	50°	1·51	1·16	23,100	—	26,800	21,400	16,800	—	19,500	15,600
9·48	60°	1·55	1·34	18,500	—	24,800	19,800	15,900	—	213,00	17,000
10·34	70°	1·56	1·47	16,000	—	23,500	18,800	15,000	—	22,100	17,700
11·18	80°	1·58	1·56	14,600	—	22,800	18,200	14,300	—	22,300	17,800
12·00	90°	1·58	1·58	14,000	—	22,100	17,700	14,000	—	22,100	17,700
JOHANNESBURG WINTER-DAY.											
7·15	5°	0·35	—	—	(19,500)	6,800	5,400	—	—	—	—
7·40	10°	0·60	—	—	(19,100)	11,500	9,200	—	5,900	3,500	2,800
8·07	15°	0·81	—	—	18,750	15,200	12,200	—	7,400	6,000	4,800
8·35	20°	0·98	—	—	18,200	17,800	14,200	—	8,500	8,300	6,600
9·45	30°	1·22	—	—	18,100	22,100	17,700	—	10,100	12,300	9,800
11·35	40°	1·35	0·87	28,800	—	25,000	20,000	18,100	—	15,700	12,600

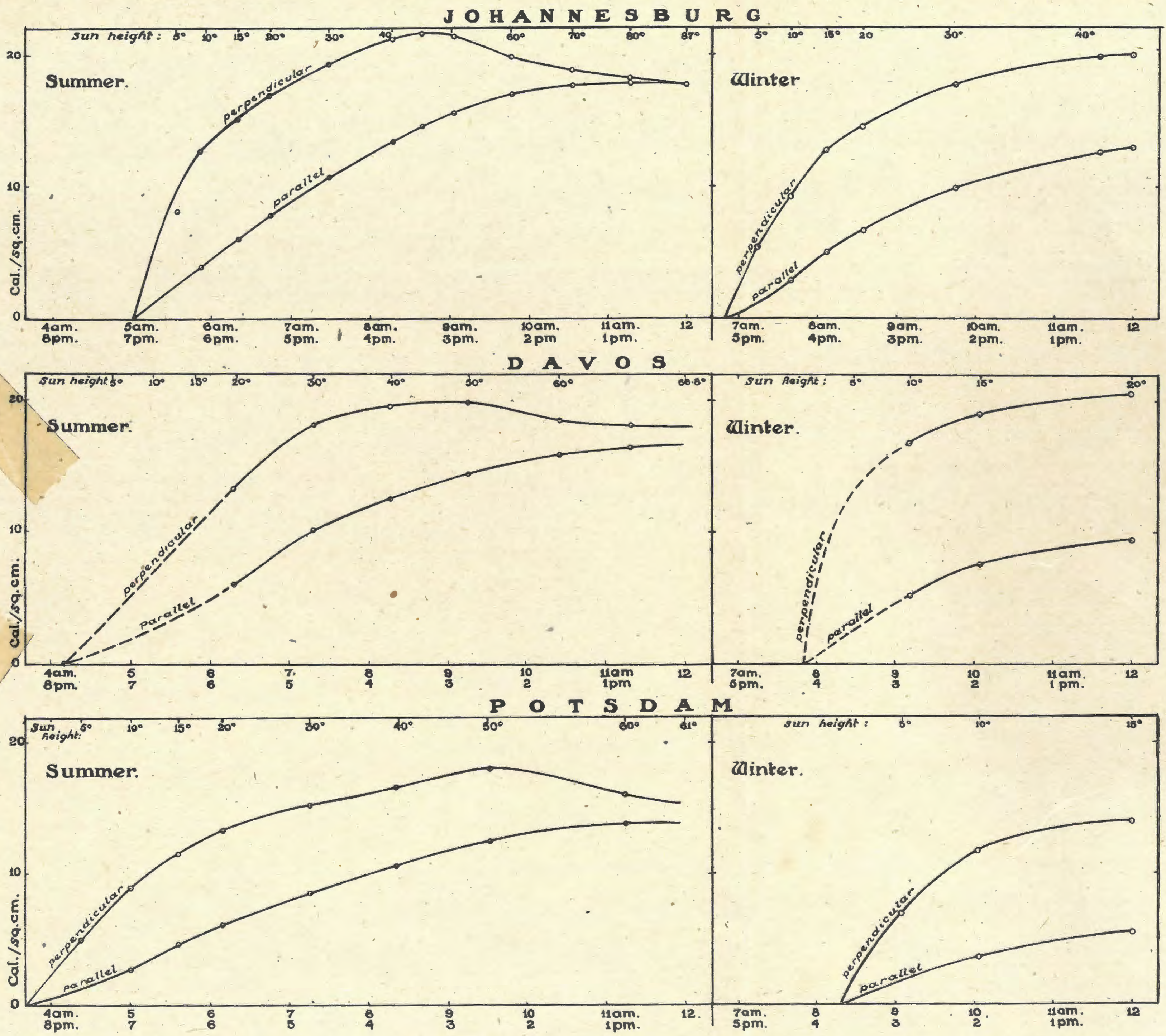

Fig. 6: The amount of direct solar radiation absorbed by a bull during a day in mid-summer and mid-winter.

6. *The total amount of radiation which is absorbed on the body surface of cattle under South African and European conditions.*

From the above items the amount of direct solar radiation absorbed on the surface of brown cattle was calculated for various altitudes of the sun for three different localities, Johannesburg, Davos and Potsdam. An example of this calculation is given for Johannesburg in Table 7. The distribution of the amount of absorbed radiation over half a mid-summer and mid-winter day is given in Figure 6. In each of the six sub-divisions two graphs are represented: the higher one indicates the total amount of direct solar radiation absorbed when the animal is standing *at right angles* to the rays, the lower graph gives the amount absorbed when the animal is *facing* the sun. The total area included under each graph represents the total amount absorbed during half a day, twice that amount gives the daily total. The respective figures are given in Table 8, column (a). To these figures have to be added the amount of absorbed radiation from the sky [Table 8, column (b)] and of the radiation reflected from the ground [column (c)]. *The total amount of radiation absorbed by the hairy coat of a bull during the whole day* is given in the last two columns of Table 8.

TABLE 8.

Amount of energy absorbed from direct solar radiation (a), sky radiation (b), radiation reflected from the ground (c), and their totals (d).

	(*a*)		(*b*)	(*c*)	(*d*)	
	Direct Solar Radiation.		Sky Radiation.	Radiation Reflected from the Ground.	Total Amount of Radiation Absorbed per Day.	
	Perpendicular.	Parallel.			Perpendicular.	Parallel.
			SUMMER.			
Johannesburg..	14·700	10·400	1·700	6·300	22·700	18·400
Davos........	14·300	8·000	1·600	5·900	21·800	15·500
Potsdam.......	13·700	8·600	3·500	5·300	22·500	17·400
			WINTER.			
Johannesburg..	9·300	4·900	0·800	2·900	13·000	8·600
Davos.........	8·300	3·100	0·300	1·200	9·800	4·600
Potsdam.......	4·500	1·500	0·400	0·600	5·500	2·500

The total amount of radiation absorbed during a whole mid-summer day on the body surface of a bull is strikingly great, namely more than 20,000 *Kilogram calories* (Cals.). Cattle of smaller size will, of course, absorb less, because their surface area is smaller. An average surface area of cattle of 990-1,200 lb. live weight is 51,000 sq. cm. (Hogan, 1923) as compared with 65,000 sq. cm. of the bull under discussion. The amount of radiation absorbed during a day will be smaller in the same proportion, assuming that the shape of different cattle is fairly similar. Consequently the amount of radiation absorbed by cattle of average size will be reduced by the ratio of the surface areas, i.e., 65,000 : 51,000 or 1 : 0·78. Instead of more than 20,000 Cals. being absorbed by the bull, smaller cattle will absorb approximately 17,000 Cals.

These quantities can perhaps best be imagined if one considers that 20,000 Cals. would suffice to heat 44 gallons of water from 0° C. to boiling point. The same amount would also suffice to increase the body temperature of the bull from normal body temperature to approximately 145° F. if heat loss were prevented. (This figure of 145° F. represents the lower limit and was arrived at by considering that 80-90 per cent. of the body consists of water with a specific heat of 1·0, and that the specific heat of the remaining parts of the body cannot be higher than unity.)

The importance of the great amount of heat absorbed by the hairy coat of cattle is also shown by comparing it with the amount of heat produced by metabolism. According to Forbes (1928) the heat production of a bull of 1,000 lb. live weight on mixed rations amounts to 9,600 Cals. per day. *During the* 15 *daylight hours of a mid-summer day the heat produced is, therefore, approximately* 6,000 *Cals., whilst* 17,000 *Cals. are absorbed on the surface of the body.* This fact emphasises the important rôle which solar radiation plays amongst the environmental influences on cattle. The loss of heat must necessarily be rendered more difficult if, during a day, the body surface absorbs about three times as much heat from radiation as is produced by the metabolism.

The different ways in which heat can be lost are the following :—

1. Loss of heat through long wave radiation, which can only take place against an environment at a lower temperature than body temperature. The greatest loss of heat takes place outwards against space. Heat is also lost by long wave radiation against objects in the vicinity of the animal, but if their temperature is higher than body temperature, heat is even gained, as for instance from the ground.

2. Loss of heat by evaporation of water, i.e., evaporation of free water from the surface of the body, the respiratory organs, and expulsion of heated water particles during expiration. These are purely physiological processes and will, therefore, not be discussed here. It may be mentioned, however, that humidity of the air influences the rate of heat loss by evaporation of water.

3. The loss of heat through conduction and convection, the rate of which is influenced by the air temperature and the wind. Air in the immediate neighbourhood of the body is heated up by the heat from the body and by convection, is replaced by cooler air. This convection takes place even if the air is absolutely calm. That wind accelerates this process is easy to understand. The significance of the figures of the difference between body and air temperature (given in Table 5, page 338) becomes immediately apparent.

From the above it can be realized that the means of losing heat are limited. An extra amount of 17-22,000 Cals. absorbed by the hairy coat from radiation must be very important in the heat regulating mechanism.

After discussing the significance of the figures in Table 8, the remaining points of interest in this table may shortly be summarized as follows:—

The total amount of radiation absorbed on the surface of a bull during a *mid-summer* day is similar, whether the animal is exposed under highveld conditions in South Africa, in the alpine regions of Switzerland or under lowland conditions in Central Europe. It is important to realize, however, that this statement does not refer to the general radiation *climate* in which the animals live in these three localities, because clear days only were used as a basis for the above calculations.

In *mid-winter*, when the difference in the angles of incidence of the rays, the duration of exposure, etc., play a bigger part in the total amount of radiation absorbed, the differences between the three localities are much more pronounced. In other words, the difference between the localities influences the mid-winter amounts of radiation more than the mid-summer amounts. In Johannesburg in mid-winter a bull would absorb about half of what it absorbs in mid-summer, in Davos a little less than half, in Potsdam only a quarter of the amount absorbed during a summer day.

The *position of the animal* with regard to the incoming solar beam influences the amount of absorbed radiation only to a small extent during a mid-summer day. In mid-winter this difference is distinctly greater. When facing the sun the animal absorbs only about half the amount of what it would absorb when standing perpendicularly to the solar beam.

7. *The reduction of the amount of radiation by natural and artificial shade.*

As pointed out above, the amount of radiation absorbed under Johannesburg conditions is about equal (summer) or greater (winter) than that absorbed under European conditions. On the other hand the difference between maximum air and body temperature at Johannesburg, for instance, and more so at Messina, is a fraction only of what it is in Davos or Potsdam. It is, of course, impossible to alter the temperature of the air, but the great amount of radiation absorbed on the body surface of cattle can be altered by providing shade. The amount of heat which has to be eliminated is then reduced predominantly to the animal's basal metabolism, except when the air temperature is so extremely high as to exceed body temperature.

To give an approximate estimate of how much of the extra heat absorbed from radiation can be eliminated by natural or artificial shade, measurements of the reducing effect of shades have been carried out at Onderstepoort. The following table contains readings of the total sun and sky radiation measured underneath a large tree, under open thorn bush and under an artificial shade created by a layer of dry branches on top of a frame. The readings were taken for ten cloudless days in each case and compared with values obtained during the same days on an instrument freely exposed to insolation. In Table 9 the total amount of incoming radiation underneath the shades is given as well as the percentage which it represents of the total amount outside the shade.

The effect of even light shading, as was obtained from the artificial shade, can be seen from the above figures. It results in a protection of the animal against 60-70 per cent. of the incoming total radiation. This would reduce the additional heat absorbed from radiation to a considerable extent. The significance of this fact need not be emphasised.

TABLE 9.

Total amount of incoming radiation in natural and artificial shade and their percentage of the radiation obtained in the open.

	RADIATION.		Percentage of the Amount in the open.
	Outside.	In Shade.	
			Per cent.
Under large tree	608	233	38
Under thornbush	458	148	38
Under artificial shade	384	147	32

SUMMARY.

Two aspects of solar radiation in its relation to cattle in South Africa and Europe are considered. The first is the solar radiation itself and the factors influencing its intensity and total amount incident on a horizontal surface at various places. The second is the question of how much radiation is absorbed by the body surface of cattle in South Africa and Europe.

A comparison of solar radiation in South Africa and Europe shows the following facts:—

1. The angle of incidence of the solar rays is distinctly larger in South Africa than in Europe.

2. The midday intensities in Davos (Switzerland) are on an average nearly equal to those at Johannesburg (South Africa); at Kew (England) they are on an average lower than at Durban (S.A.).

3. The days are shorter in South Africa during summer, but longer during winter.

4. The number of hours with bright sunshine is much greater in South Africa during the whole year, particularly during winter.

5. The monthly total amount of sun and sky radiation is equal or slightly greater in summer; it is, however, markedly greater during winter in South Africa than in Europe.

6. The yearly total amount of incident radiation is 187 Kilogram Calories per square centimeter at the South African Inland Stations as compared with 103 Cals./sq. cm. on the lowlands of central Europe.

In Part II the total absorption of radiation from the sun, the sky, and that reflected from the ground on to the body surface of cattle under South African and European conditions is calculated. The discussion is limited to a few clearly defined examples. Figures of the amount of solar and sky radiation impinging on to the animal during a clear mid-summer and a clear mid-winter day are given, the animal either standing at right angles to the solar beam or facing the sun. The absorption of the incoming radiation is determined by reflection measurements on two brown bovine hides of different breeds (Sussex × Afrikaner and high grade Afrikaner) and figures of

the absorption of direct solar and sky radiation and the absorption of radiation reflected from the ground are presented. From these data the total amount of radiation absorbed by the body surface of cattle is calculated. This amount is found to be strikingly high, e.g., more than 20,000 Kilogram Calories during a clear mid-summer day, regardless whether the animal is exposed on the highveld of South Africa, in the alpine region of Switzerland or on the lowlands of central Europe.

A comparison of the total amount of radiation absorbed by the hairy coat and the heat produced by metabolism shows that cattle absorb nearly three times as much heat from radiation as they produce by metabolism during an equal period.

The means of losing heat in order to keep their body temperature within safe limits are discussed from a physical point of view. With regard to a possible reduction of the amount of heat which has to be eliminated from the body, the effect of shade on the amount of incident radiation is discussed. Figures of the reduction of the incoming solar radiation by natural and artificial shade are given which show that the amount of heat absorbed by the hairy coat of cattle can, by providing shade, be reduced to 30-40 per cent. of the amount which impinges on to the animal in the open veld.

ACKNOWLEDGMENT.

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