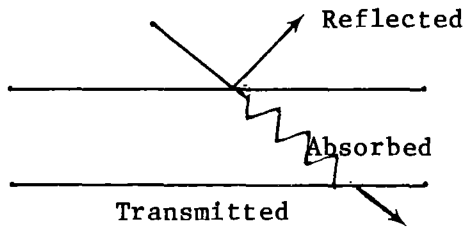
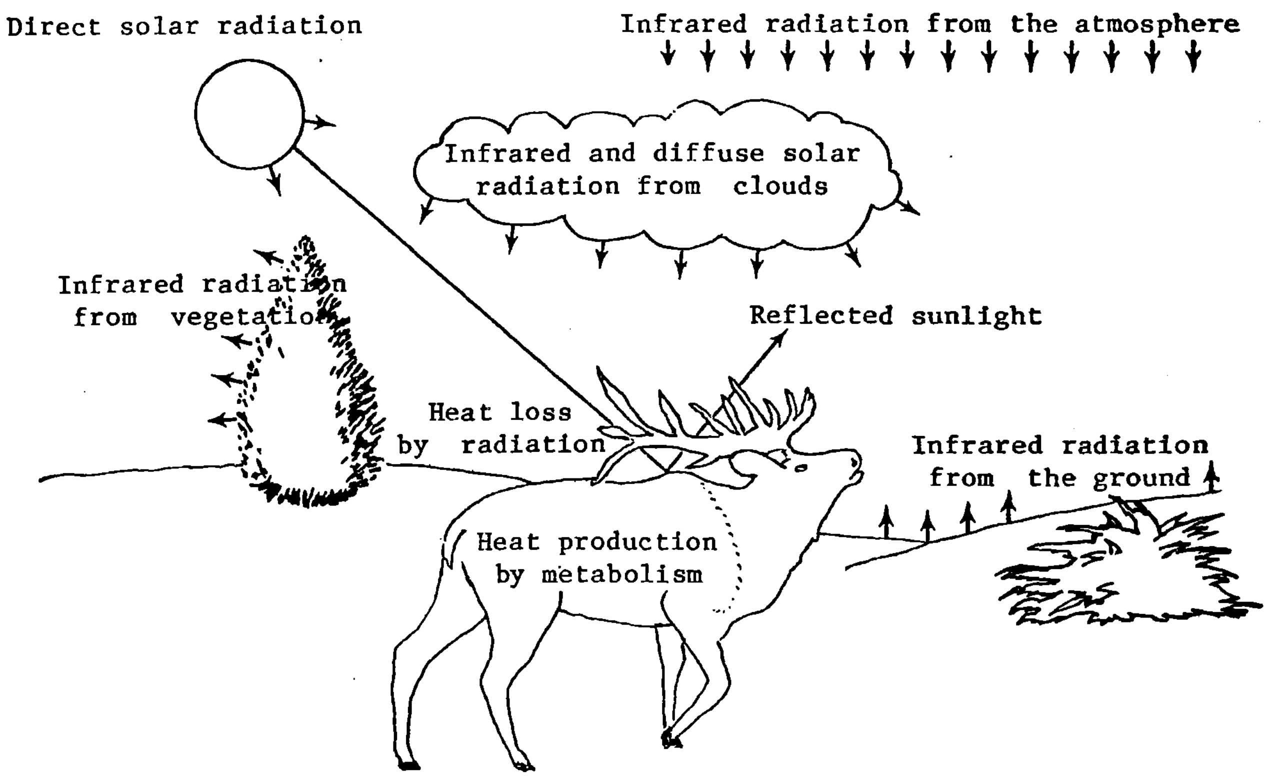
TOPIC 1: RADIATION EXCHANGE

Radiant energy follows three pathways as it travels straight-line paths from radiating sources to receiving surfaces. It may be reflected from the receiving surface, absorbed by the receiving mass, or transmitted through it. These three possibilities must be quantified when radiant energy is related to biological organisms.



Where does radiant energy come from? Every surface with a temperature above absolute zero emits radiant energy. This energy is continually being exchanged between surfaces with mutual fields of view. Two trees in a forest exchange radiant energy on even the coldest winter day. Two animals near each other exchange energy, and exchanges also occur between the ground and animals, clouds and animals, and all other surfaces within view.



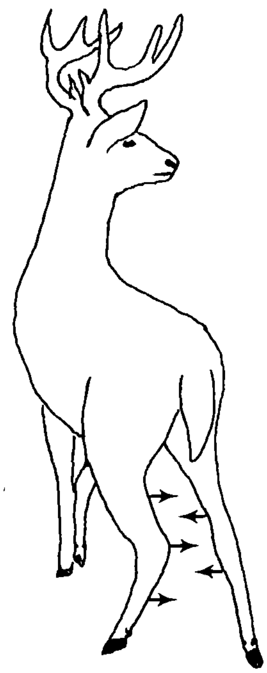
Radiant energy may be positive, negative, or equal in both directions. It is equal between two adjacent trees in the forest at night; the net exchange is zero. If one surface emits more than it receives, then the emitting surface has a negative radiation balance. If one surface receives more energy than it emits, then it has a positive radiation balance. The part of the earth illuminated by the sun has a positive radiation balance, and the dark portion usually has a negative radiation balance.

Radiation exchange would be very easy to calculate if the earth had no atmosphere, but was simply a physical surface in the vacuum of space. The moon's surface is like that, and the surfaces of the astronauts' suits were also like that. The lack of an atmosphere on the moon results in very distinct and rapid changes in its surface temperatures. Radiation exchange is the only form of heat transfer possible between the sun and the moon and the emptiness of space. The atmosphere over the earth's surface, while it may seem cold at times, ameliorates the energy balance at the earth's surface, by impeding the loss of radiant energy from the earth to space.

The atmosphere complicates the calculation of heat transfer, especially at the hairy surface of an animal. Such a hairy surface is not a single plane, so the radiant surface is difficult to define, and the hairs add to the potential for convective effects. Rather than complicate the calculations too quickly, however, radiation exchange is quantified by first discussing geometric considerations in UNIT 1.1, and then describing the absorption, reflection, and emission of radiation in the visible wavelengths in UNIT 1.2 and in the infrared wavelengths in UNIT 1.3.

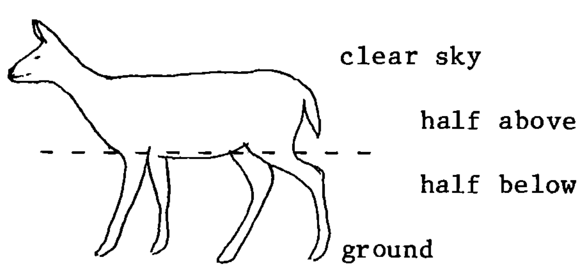
UNIT 1.1. RADIATION PROFILES

The surface area of an animal that is participating in radiant energy exchange with the external environment is not necessarily the same as the physical surface of the animal. For example, if the animal is standing, the inner surfaces of the legs exchange some infrared radiant energy with each other, and if both leg surfaces are at the same temperature, the net exchange is zero.

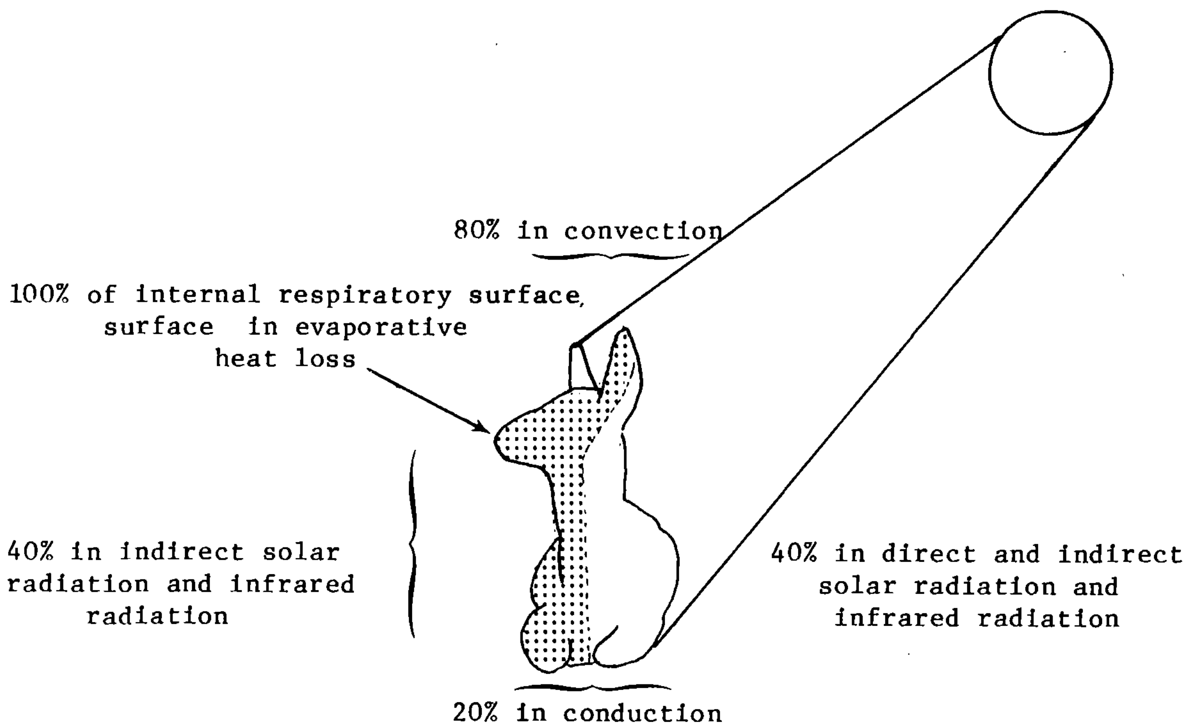


When an animal is bedded, some of the physical surface is tucked against itself. The legs, for example, may be curled up under the body and the neck and part of the head tucked alongside the trunk, reducing the total surface area exposed to radiant energy.

The radiation profile for infrared radiation is dependent not only on the animal's posture, but also on the canopy type. A deer under a clear sky exposes part of its body to the sky and part to the ground. A "half above: half below" profile may be used as a first approximation. The top half of the surface is exposed to the sky (for calculation purposes) and the bottom half to the ground. This is illustrated below, and used in a WORKSHEET in CHAPTER 16, UNIT 1.1.



Radiation profiles in the visible wavelengths are dependent on both the animal's posture and on the relative amounts of direct and diffuse solar radiation. Calculations of the solar constant and of the solar radiation at the earth's surface were made for plane surfaces oriented differently in relation to the sun's path from sunrise to sunset in CHAPTER 14. Organsims are three dimensional rather than single planes, however, so they are exposed to an infinite number of angles with respect to direct-beam solar radiation. These angles change as the sun's position in relation to the organism changes, and as organisms change their postures. There are concomitant changes in absorption coefficients as the angles of incidence change, and absorption coefficients also vary due to hair roughness and hair color. Thus every organism has a constantly-changing dynamic solar radiation profile of absorbed radiation over the entire body surface.



Some parts of the animal's surface are exposed to both direct and diffuse solar radiation, while other parts are exposed to diffuse radiation only. Atmospheric conditions also affect the relative amounts of direct and diffuse solar radiation. A completely overcast sky results in diffuse solar radiation only in the visible wavelengths. Radiation profiles are too dynamic and complex to portray in their entirety, but opportunities for estimating simplified radiation profiles are given in the WORKSHEETS that follow.

REFERENCES, UNIT 1.1

RADIATION PROFILES

SERIALS

CODEN VO-NU BEPA ENPA ANIM KEY WORDS----------------- AUTHORS---------- YEAR

odvi

CODEN VO-NU BEPA ENPA ANIM KEY WORDS----------------- AUTHORS---------- YEAR

odhe

CODEN VO-NU BEPA ENPA ANIM KEY WORDS----------------- AUTHORS---------- YEAR

ceel

CODEN VO-NU BEPA ENPA ANIM KEY WORDS----------------- AUTHORS---------- YEAR

alal

CODEN VO-NU BEPA ENPA ANIM KEY WORDS----------------- AUTHORS---------- YEAR

rata

CODEN VO-NU BEPA ENPA ANIM KEY WORDS----------------- AUTHORS---------- YEAR

anam

CODEN VO-NU BEPA ENPA ANIM KEY WORDS----------------- AUTHORS---------- YEAR

bibi

CODEN VO-NU BEPA ENPA ANIM KEY WORDS----------------- AUTHORS---------- YEAR

ovca

CODEN VO-NU BEPA ENPA ANIM KEY WORDS----------------- AUTHORS---------- YEAR

ovda

CODEN VO-NU BEPA ENPA ANIM KEY WORDS----------------- AUTHORS---------- YEAR

obmo

CODEN VO-NU BEPA ENPA ANIM KEY WORDS----------------- AUTHORS---------- YEAR

oram

CHAPTER 15 WORKSHEET 1.1a

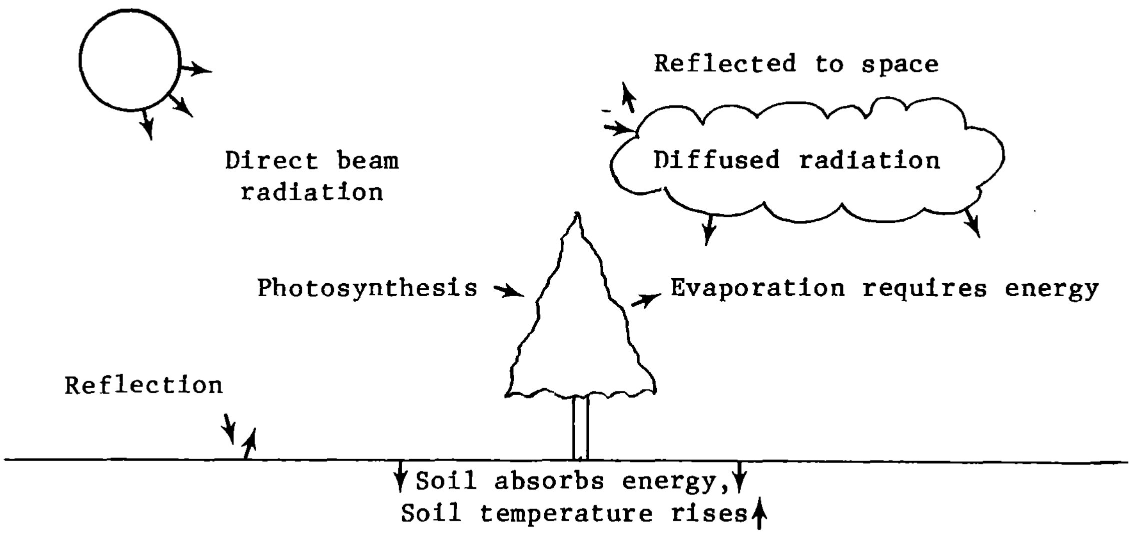
Radiation profiles

The reflection and absorption of radiant energy of different wavelengths have been illustrated in UNIT 1.1. An animal bedded in the sun, for example, might have 40% of its surface exposed to direct solar radiation, 80% exposed to indirect solar radiation, and 80% exposed to infrared radiation. Other percents of surface area are exposed to convection, conduction, and evaporation.

Sketch various postures and make estimates of the surface areas involved in infrared and visible radiation exchange. Relate these estimates to surface area calculations in CHAPTER 1. Standing, bedded with head up, and bedded with head curled back are three postures considered necessary for thermal exchange calculations.

UNIT 1.2: RADIATION EXCHANGE IN THE VISIBLE WAVELENGTHS

Measured solar radiation includes both the direct beam and the indirect radiation diffused by the atmosphere, especially by clouds. What happens to this radiation when it reaches the earth's surface?



Some of the energy is reflected from the earth back to space. The percentage of the solar radiation reflected from a surface is called the albedo of the surface. It varies both daily and seasonally due to variations in physical and biological characteristics. The elevation of the sun is very important; albedos of horizontal surfaces increase as the elevation of the sun decreases. This is illustrated by the high reflectivity of a lake's surface as sunset approaches.

The albedo of the ground surface varies seasonally with changes in snow cover; new-fallen snow has a higher albedo than old snow. There are differences due to vegetation; a dense conifer canopy has a lower albedo than a mixed hardwood canopy.

The energy that is reflected back into space is not absorbed by the earth's surface, so it cannot become part of the earth's energy balance. The energy absorbed at the earth's surface may take several pathways. Some of the energy is absorbed by the soil, resulting in an increase in soil temperature. Some of the energy drives the water cycle--evaporation requires energy. Some of the energy, usually less than 1% annually, is absorbed and used by plants for photosynthesis. These pathways represent short-term changes in energy storage. Over long periods of time, the amount of radiant energy reaching the earth's surface must equal the amount dissipated, or else the earth's surface would become increasingly warm.

Radiant energy in the visible portion of the electromagnetic spectrum is reflected from, absorbed by, and transmitted through biological tissue at rates dependent on the characteristics of the tissue and the distribution of the wavelengths. The visible wavelengths that are reflected permit animals to see each other and other components of their environment. Little is known about visual perception capabilities of wild ruminants. They apparently do not see color as humans do, which means that they do not have the neurological capabilities to discern differences between wavelengths in the visible portion of the spectrum.

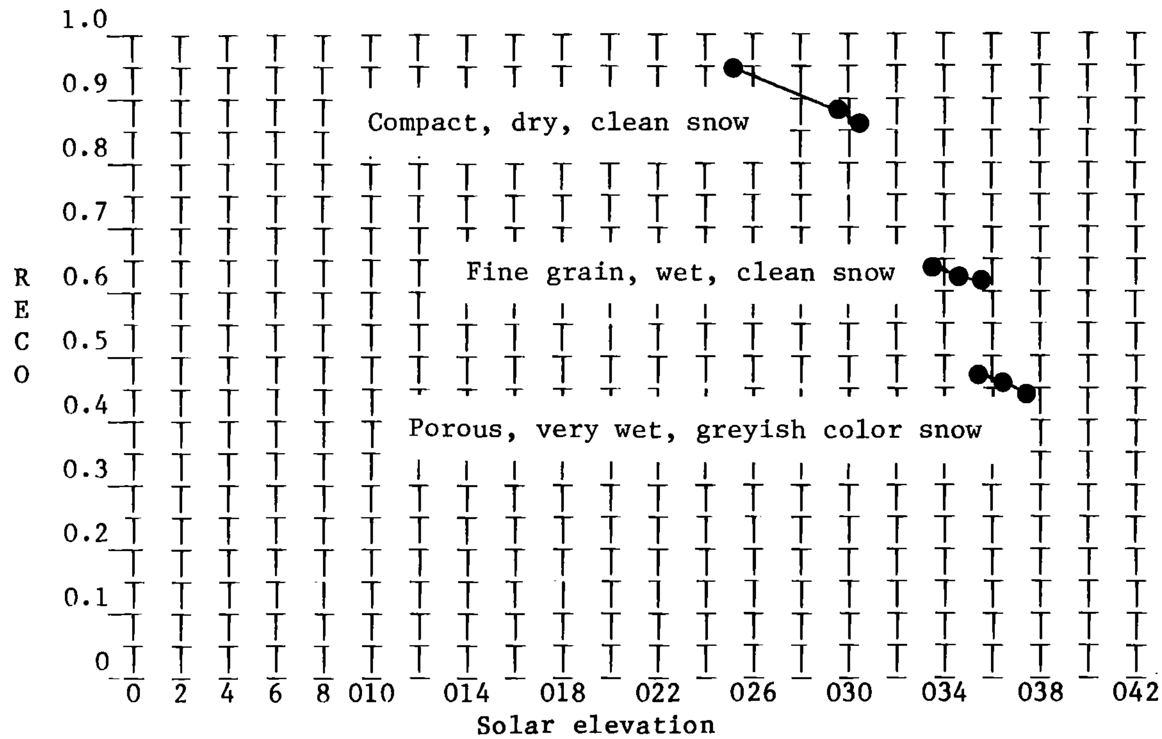
Visible wavelengths absorbed by biological tissues are converted to heat. This is of interest ecologically as absorbed energy reduces thermal gradients and heat loss between organism and environment. Animals sometimes select bedding sites and other activity areas that are thermally favorable. I observed a white-tailed deer, for example bedded on the south side of a steep-sided snowbank on a bright and sunny sub-zero day in western Minnesota. That spot was like a reflector oven, and was surely warmer than a more exposed site just meters away.

It is important, however, to remain objective when making observations such as the one above, not jumping to the conclusion that such a site was needed by the deer under those conditions. It may be that this particular site was favorable but not necessary. Careful calculations of heat exchange help one make such distinctions.

Reflection coefficients (RECO) or albedos of various surfaces are given for the visible wavelengths in the table below, modified from Satterlund (1972:97).

Surface cover	Albedo
Water	0.05-0.10
Bare soil (light colored, dry)	0.20-0.35
(dark colored, moist)	0.08-0.15
Grass (short, green,dry)	0.25-0.35
(short,green,wet)	0.15-0.20
(tall, cured)	0.25-0.30
(tall, green)	0.15-0.20
Marsh and Bogs	0.15-0.20
Forests (Spruce, dense, no snow)	0.05-0.10
(Spruce, dense, snow)	0.20-0.25
(Mixed conifer-hardwood, in leaf)	0.10-0.15
(Hardwoods, in leaf)	0.15-0.20
(Hardwoods, winter, snow)	0.35-0.45
Snow (fresh)	0.80-0.95
(old)	0.40-0.70

Reflective properties of snow are given in Gray (1970:2.27) in relation to the height of the sun. The illustration below shows the pattern of reflection coefficients in relation to solar elevation; reflectivity decreases with increasing solar elevation.



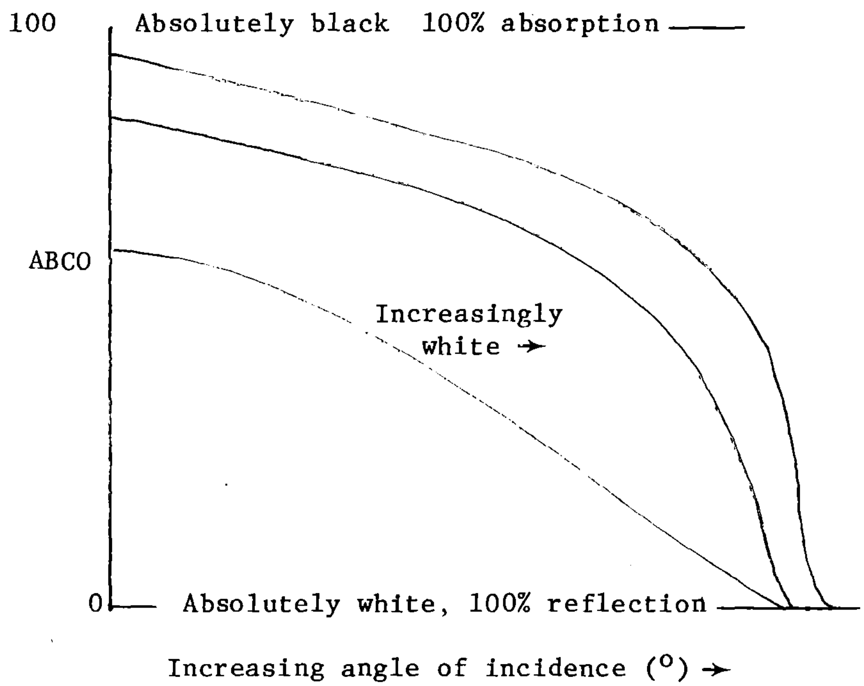
While there are data on reflection coefficients for snow, soil, and vegetation surfaces, there is a dearth of information on the reflection coefficients of the pelage of different animal species. Since mammals do not transmit radiation through their hair coats, reflection and absorption are the two ways in which radiant energy interacts with the hair surface. The absorption coefficient, ABCO, is:

$$1.00 - \text{RECO} = \text{ABCO}$$

Absorption of visible wavelengths by a smooth surface is related to the color of the surface. A white surface appears white because it reflects all of the wavelengths in the visible portion of the spectrum, and a black surface appears black because it absorbs them. The amounts reflected and absorbed determine the changes in the heat content of the tissue, of course.

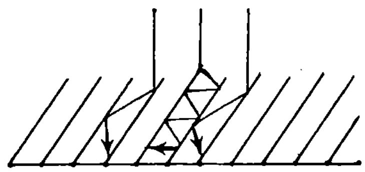
The absorption coefficient of a plane surface is dependent not only on color but also on the angle of incidence. The absorption coefficient must must go to zero when the beam of radiant energy is parallel to the surface, and it is maximum when the angle of incidence is 90°. There is a gradient between these two extremes. What is the shape of the curve expressing that gradient?

Absorption coefficients of black, brown, and white cattle have been evaluated by Riemerschmid and Elder (1945; See also Moen 1973:79). The general pattern shows a rapid drop in absorption at angles greater than 45 for white cattle, and at angles greater than 70 for brown and black cattle. The sketch below shows the general pattern of the absorption coefficient (ABCO) over a range of shades from black to white.

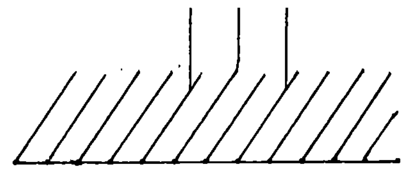


There is one very important consideration to make when evaluating the patterns above in relation to the smoothness of the hair coat. The coats of the African cattle measured by Reimerschmid and Elder were very smooth, and they responded to incident radiation as plane surfaces. The coats of most wild ruminants are very rough, especially in the winter. The roughness of the hair affects the overall absorption coefficient as each hair acts as a reflecting and absorbing surface.

Consider two hairy surfaces, one composed of white hairs and the other of black hairs, both exposed to a beam of radiation. Recall that white surfaces reflect more and absorb less of the energy in the visible wavelengths than black surfaces do. The white hairs reflect the radiant energy, and because they project outward from skin surfaces, much of the energy reaching the white hairy surface is reflected back into the hair coat towards the skin. Such reflections by individual hairs results in more absorption by the hair coat as a whole than if the hairs were black. Black hairs absorb more and reflect less radiant energy in the outer portion of the hair coat, but since this outer portion is also more exposed to the atmosphere than the inner portion, the effects of convection, both natural and forced, on the hairy surface results in the dissipation of the absorbed energy rather than absorption deeper into the hair coat where the wind penetrates less. Thus, it may be thermally more desirable to have a rough white coat than a rough black one in a cold climate.



White hairs, reflecting into hair layer



Black hairs, absorbing at tips

The effects of roughness, densities, and depths of hair coats make it clear that absorption and reflection coefficients cannot be considered on the basis of coat color alone. There are no data on these relationships for wild ruminants, however. Oritsland (1974) discusses these relationships for polar bear hair, but that is the only reference currently available on this effect.

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Oritsland, N. A. 1974. A windchill and solar radiation index for homeotherms. J. Theor. Biol. 47(2):413-420.

Riemerschmid, G. and J. S. Elder 1945. The absorptivity for solar radiation of different coloured hairy coats of cattle. Onderstepoort J. Vet. Sci. Anim. Ind. 20(2):223-234.

Satterlund, D. R. 1972. Wildland Watershed Management. Ronald Press Co. NY 370 p.

REFERENCES, UNIT 1.2

RADIATION EXCHANGE IN THE VISIBLE WAVELENGTHS

SERIALS

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS------------------	AUTHORS----------	YEAR
				odvi			

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS------------------	AUTHORS----------	YEAR
XARRA	215--	1	4	odhe	sol rad,rdnt temp,dee surf	parker,hd; drisco	1972

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS------------------	AUTHORS----------	YEAR
				ceel			

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS------------------	AUTHORS----------	YEAR
				alal			

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS------------------	AUTHORS----------	YEAR
JTBIA	47--2	413	420	rata	solar radiation, wind chil	oritsland,na	1974

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS------------------	AUTHORS----------	YEAR
				anam			

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS------------------	AUTHORS----------	YEAR
				bibi			

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS------------------	AUTHORS----------	YEAR
				ovca			

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS------------------	AUTHORS----------	YEAR
				ovda			

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
				obmo			

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
				oram			

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
ECOLA	58--6	1384	1392	doca	cattle colors, solar radia	finch,va; western	1977
JANSA	35--3	624	627	doca	phys principl, energy exch	morrison,sr	1972
JAPYA	26--4	454	464	doca	penetrance coats by radiat	hutchinson,jcd; /	1969
OJVRA	20--2	223	234	doca	absorpt, solar rad, colour	riemerschmid,g; e	1945

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
CBPAB	52--2	343	349	doru	reflectance, sol rad, coat	hutchinson,jcd; /	1975
IJBMA	20--2	139	156	doru	meteorology in animal prod	bianca,w	1976
JAPYA	37--3	443	446	doru	heat flow meters, heat los	mchinnis,sm; ingr	1974
PRLBA	188--	377	393	doru	radiati transf, anim coats	cena,k; Monteith,	1975

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
AJZOA	20--1	17	22	dosh	effec postu. heat loa, sum	dawson,tj	1972
ECOLA	50--2	328	332	dosh	bioclim compar, summer day	dawson,tj; denny,	1969
JAPYA	35--5	751	754	dosh	local heat balance, radiat	clark,ja; cena,k/	1973

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
ECOLA	45--3	646	649		sol rad char of tree leavs	birkebak,r; birke	1964

UNIT 1.3: RADIATION EXCHANGE IN THE INFRARED WAVELENGTHS

Radiation exchange in the infrared wavelengths, a function of the radiant temperatures of the surface, is calculated with the Stephan-Boltzmann law described previously, with the addition of the coefficient of infrared emissivity, IREM:

$$QREE = (IREM)(SBCO)(RATK)^4$$

where QREE = quantity of radiant energy emitted,
IREM = coefficient of infrared emissivity (discussed below),
SBCO = Stephan-Boltzmann constant = 8.127×10^{-11} cal cm^{-2} min^{-1}
= 4.876×10^{-8} kcal m^{-2} h^{-1}, and
RATK = radiant temperature in K.

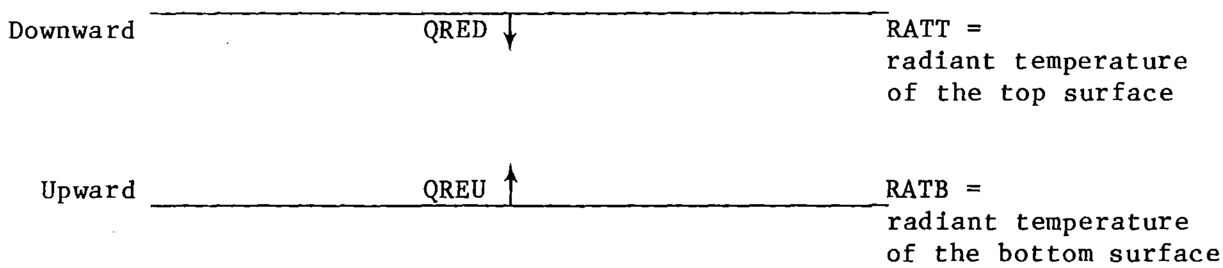
The coefficient of infrared emissivity of a surface is equal to the coefficient of absorption of that surface. In other words a surface emits infrared energy as efficiently as it absorbs it. A perfect black body not only absorbs all of the infrared energy reaching it, but also emits all that it can as a direct function of the fourth power of its absolute temperature.

A surface may be "black" at some wavelengths and grey at other wavelengths. Snow, for example, is a very poor absorber of wavelengths in the visible part of the electromagnetic spectrum, but a very good absorber and emitter of infrared energy. In fact, new-fallen snow has an absorption and emission coefficient of about 0.9 in the infrared, while its albedo, or reflection coefficient, is 0.7 or more, absorption is 0.3 or less, in the visible part of the solar spectrum. Aged snow has a lower infrared absorption coefficient, and a lower solar albedo as well.

Infrared absorption and emission coefficients of hairy surfaces are not highly variable. They are usually 0.8 or more, and often approach 1.0. In fact, 1.0 is a satisfactory approximation for hair, regardless of its color.

All surfaces in the biosphere are constantly exchanging infrared energy with neighboring surfaces within their field of view. Suppose two parallel surfaces are oriented horizontally. The downward flux is determined by using the formula:

$$QRED = (IREM)(SBCO)(RATK)^4$$



The upward flux is determined by using the formula:

$$QREU = (IREM)(SBCO)(RATB)^4$$

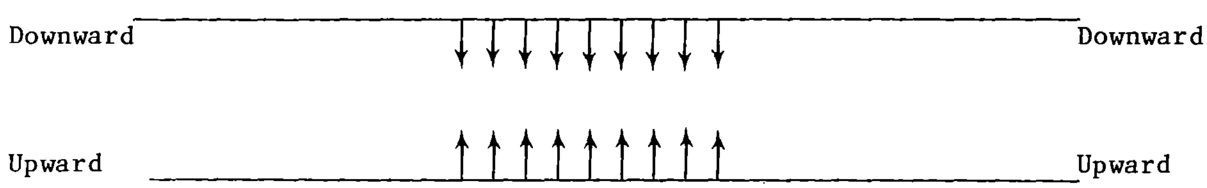
The total flux is the sum of the two:

$$QRET = QRED + QREU = [(IREM)(SBCO)(RATT)^4] + [(IREM)(SBCO)(RATB)^4]$$

The net flux is the difference between the two:

$$QREN = QRED - QREU = [(IREM)(SBCO)(RATT)^4] - [(IREM)(SBCO)(RATB)^4]$$

Suppose that an object or organism was situated in the flux between the top and bottom surfaces illustrated above. This could be a leaf on a tree exposed to the sky (top) and the ground (bottom). The leaf absorbs energy from both directions as ilustrated below, and its temperature will rise in relation to the net energy absorbed. The leaf, however, also emits energy.



How much radiant energy must the leaf emit to remain in radiation equilibrium? If the heat energy is equally distributed throughout the leaf, equal amounts could be emitted from both the upper and lower surfaces. Divide the total radiant energy flux by 2: TREF/2. Then, rearrange the equation to determine the effective radiant temperature of the leaf (ERTL) with the formula:

$$ERTL = \sqrt[4]{(TREF/2)/SBCO}$$

The energy emitted from the leaf, considering both surfaces, may be calculated with the effective radiant temperature of the leaf. It is numerically equal to the total amount absorbed if the leaf temperature does not change. Some radiant "surfaces" are infinite heat sinks, and others are not. The clear sky, for example, is an infinite heat sink; its radiant temperature does not change as a result of dissipation from the earth's surface. Leaf temperatures, however, do change as radiation is absorbed or emitted and there is a finite limit to the quantity of heat energy that can be present in a leaf.

A similar approach may be used for calculating the exchange between two animal surfaces or between an animal's surface and its radiant thermal environment. Radiant surface temperatures of an animal are dependent on several external factors, including the variable amounts of solar radiation absorbed over the hair surface, the air temperature, and the wind velocities over the animal's surface. In general, surface temperatures increase as more solar radiation is received and decrease as air temperature decreases and wind velocity increases. Wind has non-linear effects as changes at low wind velocities cause greater changes in surface temperature than changes at high velocities. The effects of greater changes at low wind velocities are ecologically important because animals are generally exposed to low velocities when in vegetative cover. Further, turbulent air movement results in fluctuating velocities, with concomitant changes in radiant surface temperatures. Changes in radiant surface temperatures are due to convection, discussed in the next TOPIC.

The radiant surface temperatures of white-tailed deer pelage exposed to wind velocities from 0 to 14 miles per hour (0 - 5 km per hour) were determined in the Thermal Environment Simulation Tunnel at Cornell's Wildlife Ecology Laboratory by Stevens (1972). Linear regression equations, where RATC = radiant temperature in °C and AITE = air temperature in °C are given below.

Mi Hr^{-1}	Combined Regressions	n	r
0	RATC = 9.49 + 0.75 AITE	51	0.98
1	RATC = 9.18 + 0.76 AITE	68	0.98
2	RATC = 8.60 + 0.78 AITE	71	0.98
3	RATC = 7.88 + 0.79 AITE	45	0.98
4	RATC = 7.53 + 0.80 AITE	74	0.97
6	RATC = 6.45 + 0.83 AITE	75	0.98
8	RATC = 5.63 + 0.85 AITE	45	0.98
10	RATC = 4.88 + 0.87 AITE	74	0.99
14	RATC = 4.05 + 0.89 AITE	52	0.98

Note how the intercepts (a values) decrease as wind velocities increase. A single equation has been derived for all of these equations by expressing a and b as functions of wind velocity. The equation is:

$$RATC = (9.483 - 0.477\ WIVE) + [(0.752 + 0.012\ WIVE)(AITE)]$$

This equation is evaluated in WORKSHEET 1.3e that follows.

Radiant temperatures have not been measured for many species of wild ruminants. Mule deer radiant temperatures were similar to those for white-tailed deer (Moen 1974). Parker (1972) measured radiant temperatures of mule deer to be -7°C at night when the air temperature was -18°C. The slope of the regression line was such that the effective radiant temperature and air temperature intersected at about +6°C. This is not expected; the theoretical intersection should be at body temperature, or about 37°C. Marble (1967) has puzzling results also; radiant temperatures were less than air temperatures at times in her studies of bison, mule deer, and pronghorn. The only physics explanation for such results is that the sky was acting as a radiant heat sink, and the body surface cooled below air temperature. This has not proven likely in my detailed measurements on live and simulated deer, and on bear. The atmosphere surrounds the animal and its fur surface, thus <u>adding</u> heat energy to the surface. Indeed, radiometers are designed to prevent the warming of the sensors by the use of polyethylene shields. Leaf temperatures have been observed to go below air temperature, but leaves do not have internal temperatures of 37-39°C. Calculations of radiant temperature and the effects of wind result in interactions between radiation and convection. Additional complexities arise from the animals' surface area configuration and the distribution of infrared flux from the environment. These are discussed in CHAPTER 16.

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Stevens, D. S. 1972. Thermal energy exchange and the maintenance of homeothermy in white-tailed deer. Ph.D. Thesis, Cornell Univ. Ithaca, N. Y. 231 p.

REFERENCES, UNIT 1.3

RADIATION EXCHANGE IN THE INFRARED WAVELENGTHS

SERIALS

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
JRMGA	27--5	401	403	odvi	radiant temp, hair surface	moen,an	1974
JWMAA	32--2	338	344	odvi	surf temp, radiant heat lo	moen,an	1968
JWMAA	38--2	366	368	odvi	radiant temp surface, wind	moen,an; jacobsen	1974

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
				odhe			

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
				ceel			

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
				alal			

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
NJZOA	19--1	89	91	rata	surf tmps, heat los, summe	wika,m; krog,j	1971
ZOLZA	53--5	747	755	rata	[body surface heat emissi]	segal,an; ignatov	1974

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
				anam			

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
				bibi			

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
				ovca			

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
				ovda			

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
				obmo			

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
				oram			

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
ECOLA	58--6	1384	1392	doca	cattle colors, heat stress	finch,va; western	1977
JANSA	35--3	624	627	doca	physic principl energ exch	morrison,sr	1972
JAPYA	26--4	454	464	doca	penetrance coats by radiat	hutchinson,jcd; /	1969

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
IJBMA	20--2	139	156	doru	meteorology in animal prod	bianca,w	1976
JAPYA	37--3	443	446	doru	heat loss, heat flow meter	mcginnis,sm; ingr	1974
PRLBA	188--	377	394	doru	radiati transf, anim coats	cena,k; monteith,	1975

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
JAPYA	35--5	751	754	dosh	local heat bal coat, cloth	clark,ja; cena,k/	1973

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
ECOLA	49--1	145	147		thermal energ exchan, tree	moen,an	1968
ECOLA	50--2	329	332		microclim compar, summer d	dawson,tj; denny,	1969
JOMAA	37--3	375	377		infra emis of arctic fauna	hammel,ht	1956
SCIEA	166	115	117		therm rad in metab chamber	porter,wp	1969

Infrared radiation in relation to the radiant temperature of the surface

The formula for calculating the quantity of radiant energy emitted, QREE, is:

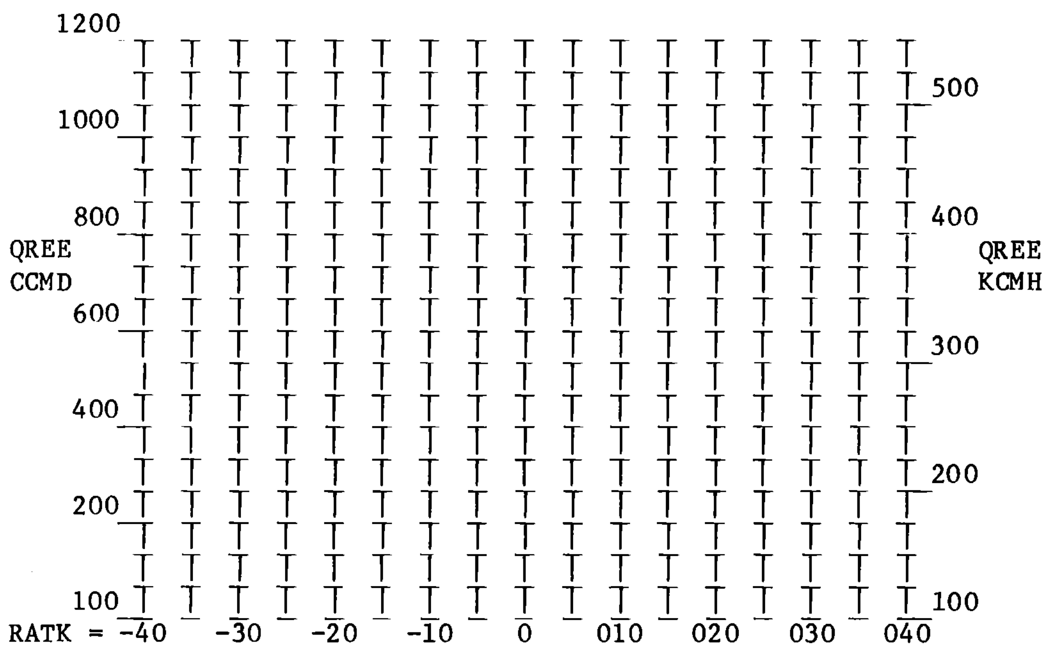
$$QREE = (SBCO)(RATK^4)$$

where RATK = radiant temperature in Kelvin degrees.
If QREE is in cal cm^2 min^{-1}, then SBCO = 1.170×10^7
If QREE is in kcal m^2 hr^{-1}, then SBCO = 4.876×10^{-8}.

Equivalent temperatures in Celsius and Kelvin degrees are:

-40 C	= 233.2 K
-30	= 243.2
-20	= 253.2
-10	= 263.2
0	= 273.2
10	= 283.2
20	= 293.2
30	= 303.2
40	= 313.2

Substitute these temperatures in the formula above and complete the nomogram. Note that the left-hand scale is in cal cm^{-2} day $^{-1}$, and the right-hand one in kcal m^{-2} hr^{-1}.



CHAPTER 15 - WORKSHEET 1.3b

Infrared radiation measurements, Suomi Radiometer

Infrared radiation measurements may be made with home-made radiometers designed by Suomi and Kuhn (1958) and discussed further in Moen (1973). The instruments I made (see Moen 1973:91) were of wood, fiberglass insulation, polyethylene, and aluminum foil, with a highly absorbent black print on the aluminum foil sensing surface and thermometers as temperature sensors.

The formulas for calculating radiation are:

$$QRED = [(IREM)(SBCO)(ABTT^4) + (ABTT - ABTB)\ KCOI + (ABTT - ABTB)\ KCOA]$$

$$QREU = [(IREM)(SBCO)(ABTB^4) + (ABTB - ABTT)\ KCOI + (ABTB - ABTT)\ KCOA]$$

where QRED = Quantity of radiant energy downward in kcal m^{-2} m^{-1}
QREU = Quantity of radiant energy upward in kcal m^{-2} m^{-1}
IREM = Infrared emissivity = 1.0
SBCO = Stefan-Boltsmann constant = 49.3×10^{-9}
ABTT = Absolute temperature of the top sensor (add 273.2 to measured C temperature)
ABTB = Absolute temperature of the bottom sensor

KCOI = Conductivity coefficient of the insulation = 0.3 for my instrument
KCOA = Conductivity coefficient of the air = a + b (IART), where
a = 1.62877,
b = 0.00516, for my instrument, and
IART = instrument air temperature which may be estimated as the temperature midpoint between air temperature and sensor temperature.

The KCOI value is dependent on the insulation used, and the equation for KCOA is dependent on the depth of the air spaces.

Instruments may be built with locally-available materials and the appropriate numerical values used in the formulas for radiation flux. Equations for given instruments may be programmed on calculators and the infrared radiation flux quickly determined from thermometer readings. These instruments are economical, portable, and very simple to use when properly designed.

LITERATURE CITED

Moen, A. N. 1973. Wildlife Ecology. W. H. Freeman Co. San Francisco. 458 p.

Suomi, V. E. and P. M. Kuhn. 1958. An economical net radiometer. Tellus 10(1):160-163.

Infrared radiation in open snow fields

Measurements of downward and upward infrared radiation in open snowfields have been made in Minnesota and New York (Moen and Evans, 1971) and equations given for the radiant temperatures of the sky and earth's surfaces. These temperatures are plotted in Moen (1973:82). The differences between sites are not great, and the data from the different sites can be combined into a single equations for the radiant temperature of the clear sky (RTSK) and the earth's surface (RTEK). The equations are:

$$\mathrm{RTSK} = (1.103\ \mathrm{AITE} - 8.915) + 273.2$$
$$\mathrm{RTEK} = (1.030\ \mathrm{AITE} - 0.049) + 273.2$$

Substituting these equations into the formula for calculating the quantity of infrared radiation emitted (in kcal per square meter per hour):

$$\mathrm{QREE} = 4.876 \times 10^{-8}\ \mathrm{RATK}^4$$

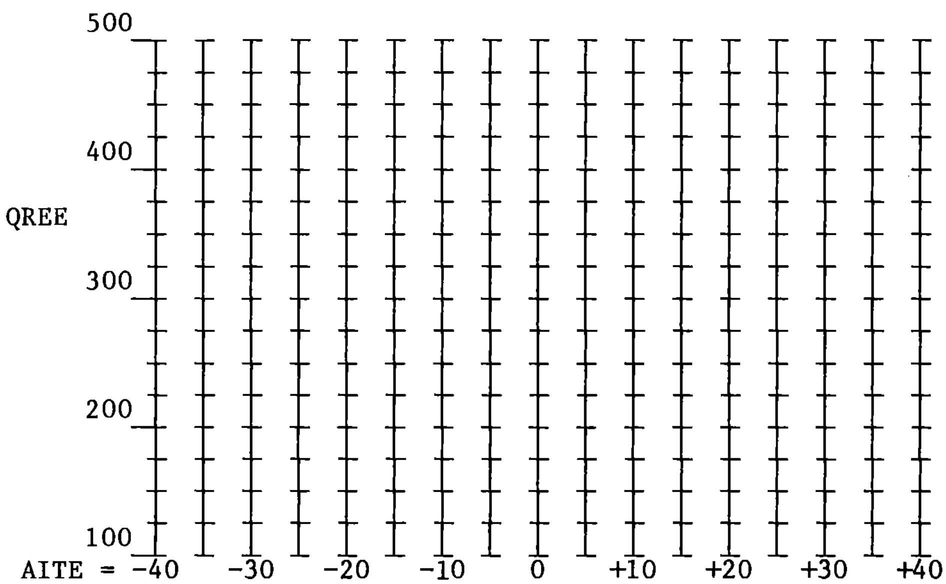
The equation for the quantity of radiant energy from the sky (QRSK) is:

$$\mathrm{QRSK} = [4.876 \times 10^{-8}][(1.103\ \mathrm{AITE} - 8.915) + 273.2]^4$$

The equation for the quantity of radiant energy from the earth is:

$$\mathrm{AREA} = [4.876 \times 10^{-8}][1.030\ \mathrm{AITE} - 0.049) + 273.2]^4$$

Complete the calculations and plot the results below.



LITERATURE CITED

Moen, A. N. 1973. Wildlife Ecology. W. H. Freeman and Co., San Francisco. 458 p.

Moen, A. N. and K. E. Evans. 1971. The distribution of energy in relation to snow cover in wildlife habitat. Pages 147-162 In A. O. Haugen ed.), Proceedings of the Snow and Ice in Relation to Wildlife and Recreation Symposium. Iowa Coop. Wildl. Res. Unit, Iowa St. Univ., Ames. 23 p.

CHAPTER 15, WORKSHEET 1.3d

Infrared radiation in different cover types

The amounts of infrared radiation flux in different cover types are dependent on the density of the vegetation, the temperature of the vegetation surfaces, and the emissivity of the surface. Densities vary from open fields, with no canopy, to dense coniferous canopies. Temperatures on the vegetative surfaces at night are close to air temperature. Emissivities are essentially 1.0. Thus the most important factor determining the radiation flux in different cover types is canopy density, with the flux in each of the different cover types a function of air temperature.

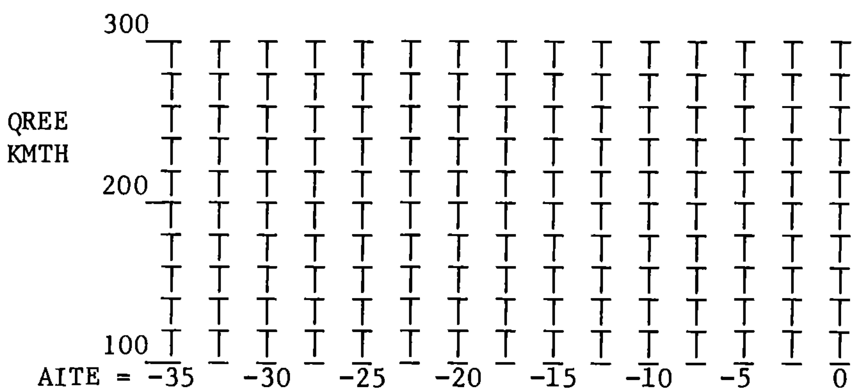
Equations for downward radiation flux in an open field, leafless hardwoods (winter), and cedar canopy are given in Moen (1968:340). The published equation is lacking σ. Substituting AITE = air temperature for X in the published equations, the new equations for quantity of radiant energy emitted (QREE) are:

$$\text{QREE} = \text{SBCO}[(-10.9 + 1.000\ \text{AITE}) + 273.0]^4 \quad \text{(open field)}$$

$$\text{QREE} = \text{SBCO}[(-5.6 + 0.964\ \text{AITE}) + 273.0]^4 \quad \text{(hardwood)}$$

$$\text{QREE} = \text{SBCO}[(+0.2 + 0.962\ \text{AITE}) + 273.0]^4 \quad \text{(cedar)}$$

Complete the calculations and plot the results below.



LITERATURE CITED

Moen, A. N. 1968. Surface temperatures and radiant heat loss from white-tailed deer. J. Wildl. Manage. 32(2):338-344.

CHAPTER 15, WORKSHEET 1.3e

Radiant temperatures of white-tailed deer

An equation for predicting the radiant temperature of white-tailed deer exposed to different wind velocities was discussed on pages 17-20. The equation from page 19 is:

$$RATC = (9.483 - 0.477\ WIVE) + [(0.752 + 0.012\ WIVE)(AITE)]$$

Determine the radiant temperature for different combinations of AITE and WIVE and tabulate below. Correct RATC to RATK.

AITE	WIVE	RATC	RATK
____	____	____	____
	____	____	____
	____	____	____
	____	____	____
	____	____	____
____	____	____	____
	____	____	____
	____	____	____
	____	____	____
____	____	____	____
	____	____	____
	____	____	____
	____	____	____
	____	____	____
____	____	____	____
	____	____	____
	____	____	____
	____	____	____
	____	____	____

AITE	WIVE	RATC	RATK
____	____	____	____
	____	____	____
	____	____	____
	____	____	____
	____	____	____
____	____	____	____
	____	____	____
	____	____	____
	____	____	____
	____	____	____
____	____	____	____
	____	____	____
	____	____	____
	____	____	____
	____	____	____
____	____	____	____
	____	____	____
	____	____	____
	____	____	____
	____	____	____

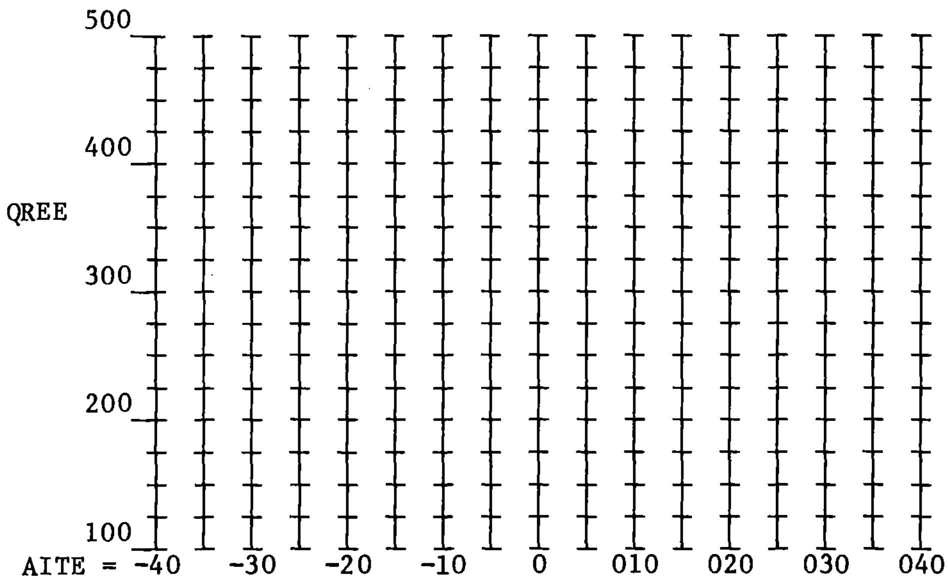
CHAPTER 15, WORKSHEET 1.3f

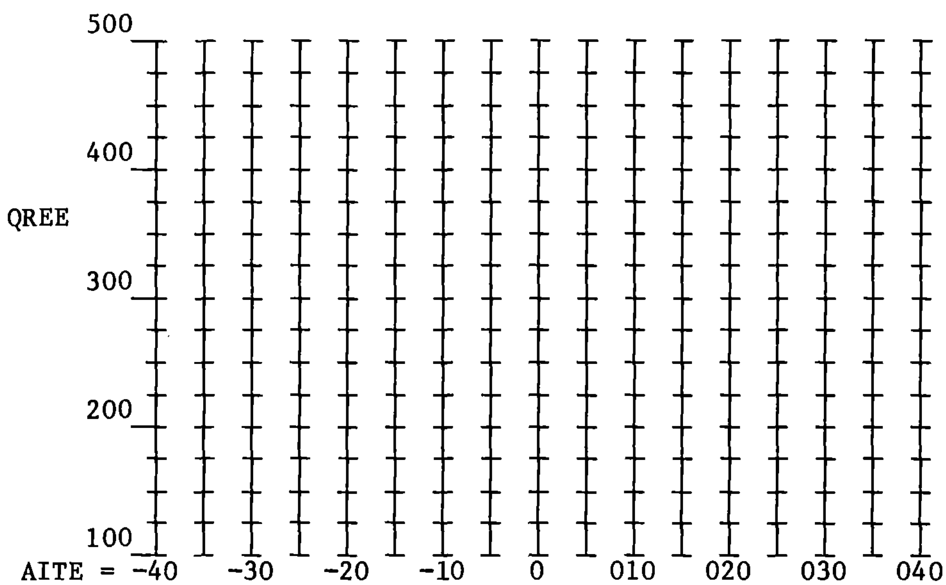
Infrared energy emitted by white-tailed deer

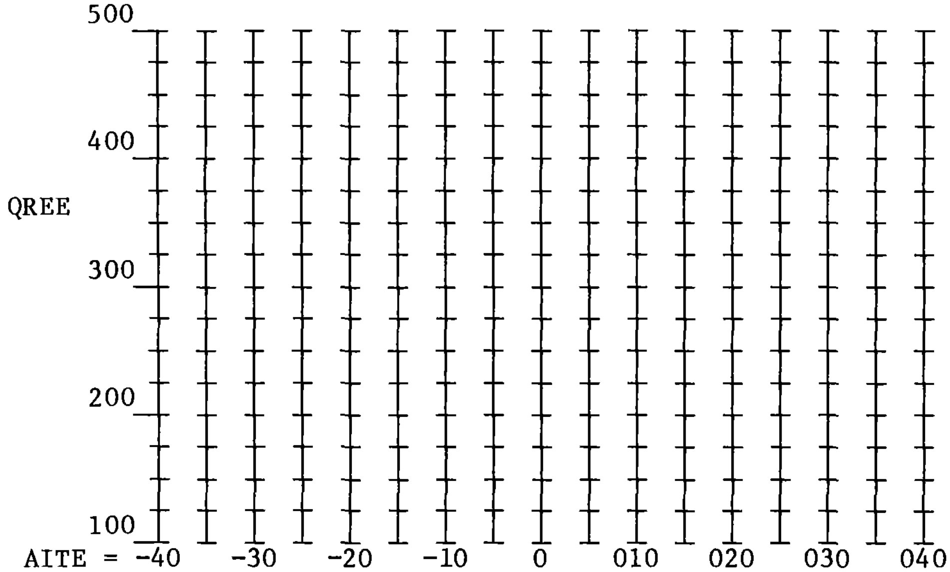
Using the radiant temperature results from the previous WORKSHEET, calculate infrared energy using the formula for QREE in WORKSHEET 1.3c.

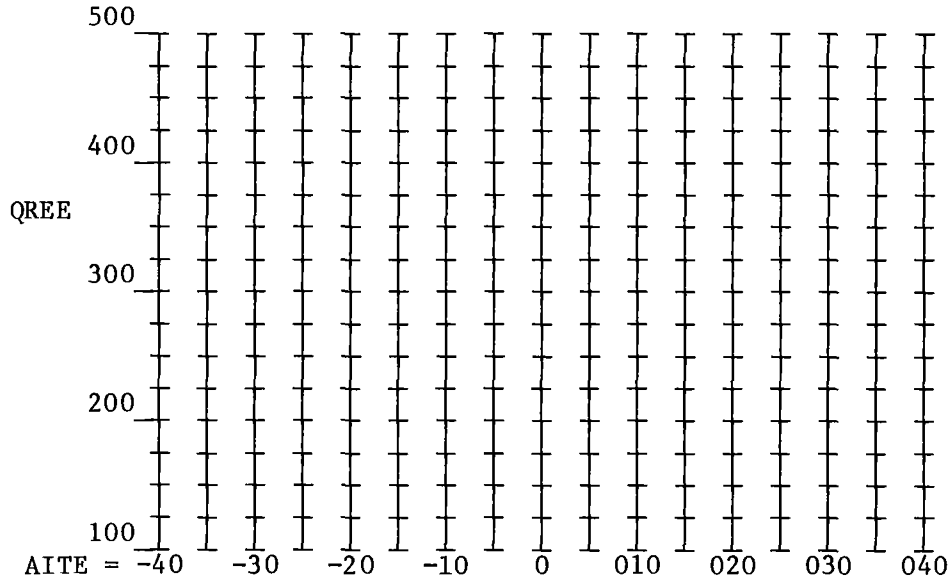
$$QREE = 4.876 \times 10^{-8} \ RATK^4$$

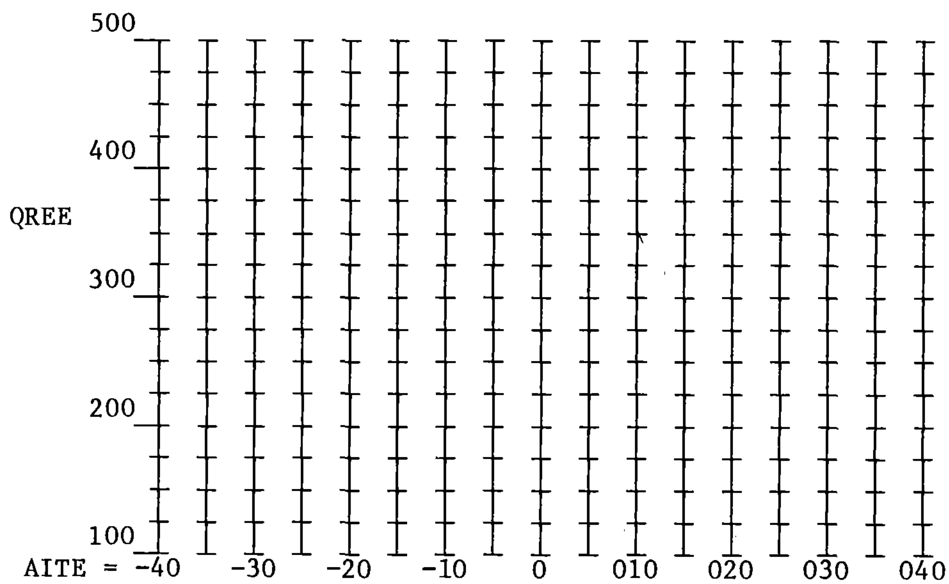
Plot the results in the grids below and on the next page. Label each line you plot with the appropriate WIVE.






500
400
QREE
300
200
100
AITE = -40
-30
-20
-10
0
010
020
030
040


500
400
QREE
300
200
100
AITE = -40
-30
-20
-10
0
010
020
030
040


500
400
QREE
300
200
100
AITE = -40
-30
-20
-10
0
010
020
030
040