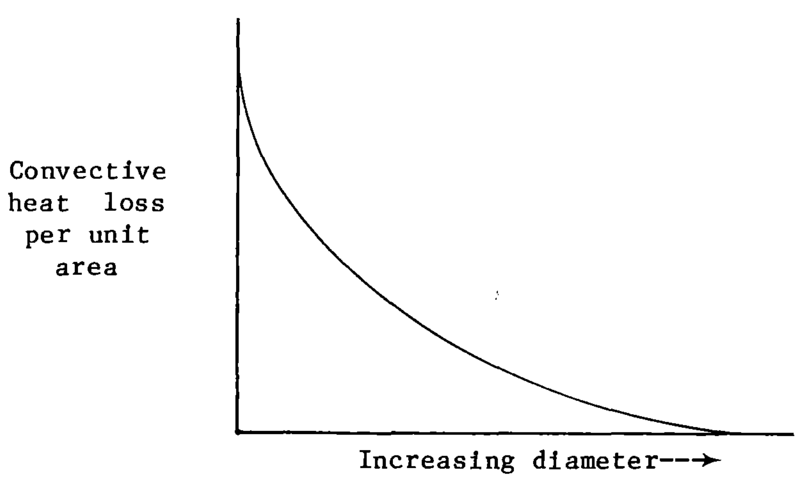
TOPIC 2. CONVECTION

Convection is the transfer of heat by the movement of a fluid across the surface of an object, or convector. Sometimes the fluid movement is generated by temperature, and hence density differences, in the fluid itself. This is called natural, or free convection. If the sun is shining on a bedded deer, for example, the deer's hair absorbs some of the solar energy and is warmed. The warmer air near the surface of the hair becomes less dense and rises and cooler air replaces it. Free convection currents are occurring over the deer's surface. Fluid (air in this case) movement generated by pressure differences external to the fluid-convector interface is called forced convection. Wind, or general atmospheric motion, is natural convection over the earth's surface, and it causes forced convection over the surface of plants, animals, and physical objects on the earth's surface.

Every plant and animal exposed to the atmosphere or liquid water is participating in natural or in forced convection. Their vertical dimensions place their surfaces in different parts of the wind profiles discussed earlier, and the movement of air is very complex because of turbulence. As a result, convection can also be expected to be a complex process. It can, however, be considered conceptually with some expressions of basic patterns.

What do you think the pattern of convective heat loss looks like for convectors of different sizes? Convectors with very small diameters are very efficient convectors, and those with larger diameters are less efficient. Convection coefficients are used to express the rate of heat transfer from the convector to the atmosphere. They have been calculated for smooth surfaces by thermal engineers, and vary with the size and shape of the convector. Smooth cylinders certainly do not approach the geometric complexities of plants and animals, however, nor do they account for the effects of rough hair insulation. The use of these coefficients does help us understand the effects of wind on plants and animals, and may be used to illustrate the process of convection. Note in the drawing below that small increases in convector diameter result in rapid declines in the heat loss per unit area.



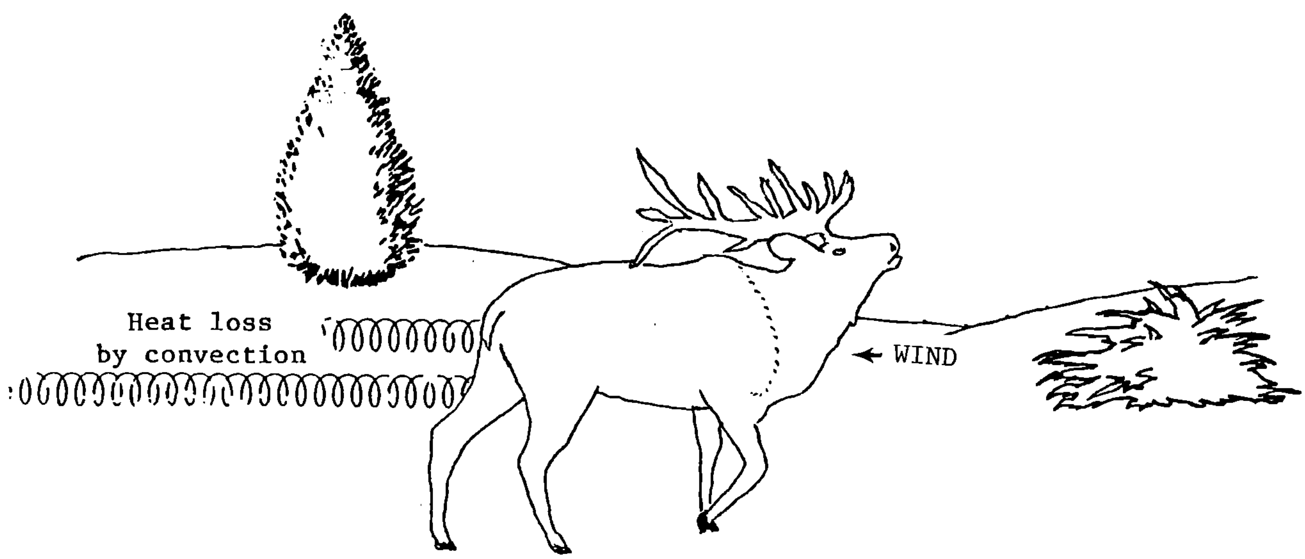
The quantity of convective heat loss (QCVE) can be expressed conceptually with the formula:

$$QCVE = (COCO)(SUTE - AITE)(SACV)$$

where QCVE = convective heat loss,
COCO = convection coefficient,
SUTE = surface temperature,
AITE = air temperature, and
SACV = surface area of the convector.

The efficiency of the convector, a function of its geometry, is expressed by the convection coefficient. The actual amount of convection is a function of the temperature difference between the convector and the air moving past it and the surface area of the convector.

It is interesting to consider the idea that every animal, every moment of its life, participates in convective heat exchange, yet there are no measurements of this process. The wind blows, and we tend not to know where it comes from or where it goes, and often pay little attention to what it does.



UNIT 2.1: NATURAL CONVECTION

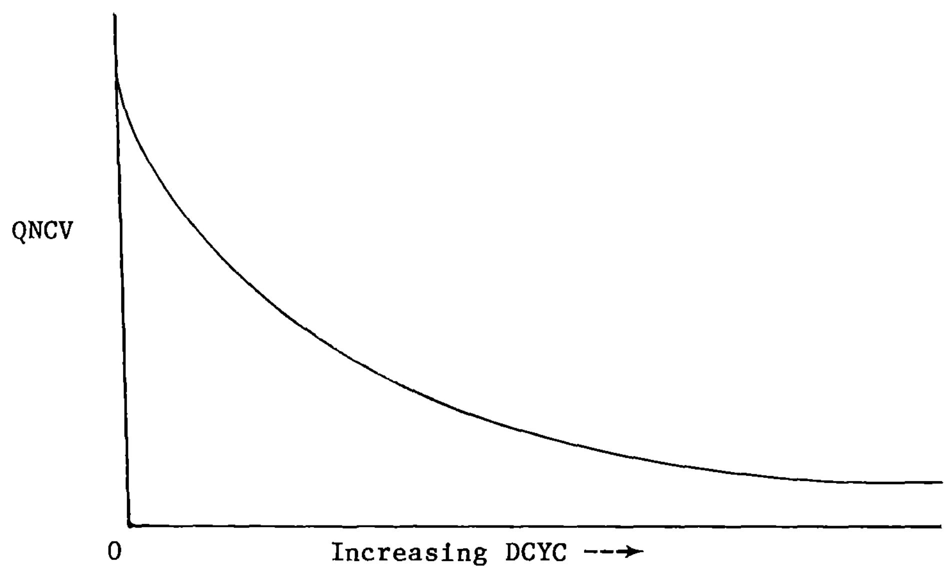
Natural, or free convection is a form of heat loss due to fluid movements resulting from temperature and density differences in the thermal boundary region. Warmer air near the animal rises, taking the heat absorbed from the animal's surface with it. Thus, a warm animal in cool, still air has a "plume" that rises into the atmosphere above the animal.

The transfer of heat energy by free convection may be estimated from three variables, including the geometric characteristics of the convector, the convection coefficient, and temperature differences between the surface and the atmosphere. The general formula for natural convection from horizontal or vertical cylinders in laminar flow, modified from Rosenberg (1974:81) is:

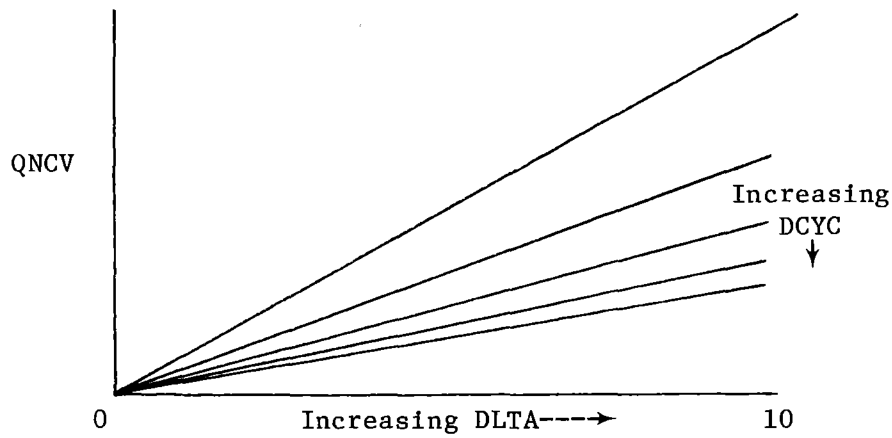
$$QNCV = 3.516\ (DLTA/DCYC)^{1/4}\ SANC$$

where QNCV = quantity of natural convection in kcal $m^{-2}\ hr^{-1}\ °C^{-1}$,
DLTA = Delta T = temperature difference in °C between the convective surface temperature and the surrounding air,
DCYC = diameter of the cylinder in cm, and
SANC = surface area involved in natural convection (in square meters; see UNITS for QNCV).

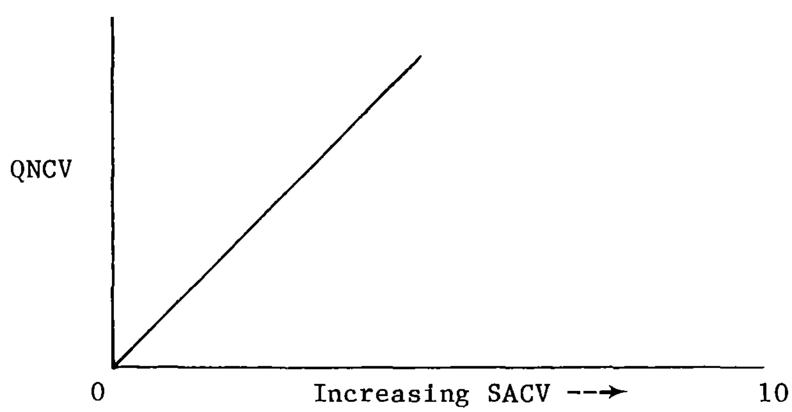
Cylinder diameter effects. The illustration below shows the effects of cylinder diameter on the pattern of natural convection. Note that the greatest amount of change in the amount of natural convection occurs at the smallest diameters. Small cylinders are more closely coupled to the effects of natural convection than are larger ones; that is mathematically expressed with the 1/4 power function in the formula.



Temperature differences. The illustration below shows that for each cylinder diameter, the effects of temperature differences are linear; each of the lines is straight. The spacings between the lines for different DCYC are unequal due to the effect shown of cylinder diameter discussed in the previous paragraph.



Surface area. As the surface area of a convector increases, the heat lost by natural convection increases if the diameter of the convector remains constant. Changes in surface area are then due to changes in length alone. The differences themselves are directly proportional to changes in length and resulting surface area since SACV is the final component of the formula and functions as a simple multiplier. If changes in area are due to changes in diameter but not length, then SACV is on the X-axis and QNCV is on the Y-axis. If changes in both diameters and surface areas occur, an infinite number of combinations of these two parameters could occur; the X:Y:Z axis are SACV:QNCV:DCYC.



Opportunities for calculations of various combinations of inputs for variables are provided on the WORKSHEETS that follow.

LITERATURE CITED

Rosenberg, N. J. 1974. Microclimate: The Biological Environment. John Wiley & Sons, N.Y. 315 p.

REFERENCES, UNIT 2.1

NATURAL CONVECTION

SERIALS

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
JRMGA	27--5	401	403	odvi	radiant temp, hair surface	moen,an	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
				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			

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 flow meters, heat los	mcginnis,sm; ingr	1974

CHAPTER 15, WORKSHEET 2.1a

Natural convection as a function of the diameter
of the convective cylinder

The formula from Rosenberg (1974:81) for the quantity of natural convection (QNCV) may be used to calculate the effects of the diameter of the convecting cylinder by using the value 1.0 for DLTA and SANC (see UNIT 2.1). The formula:

$$QNCV = 3.516\ (DLTA/DCYC)^{0.25}\ SANC$$

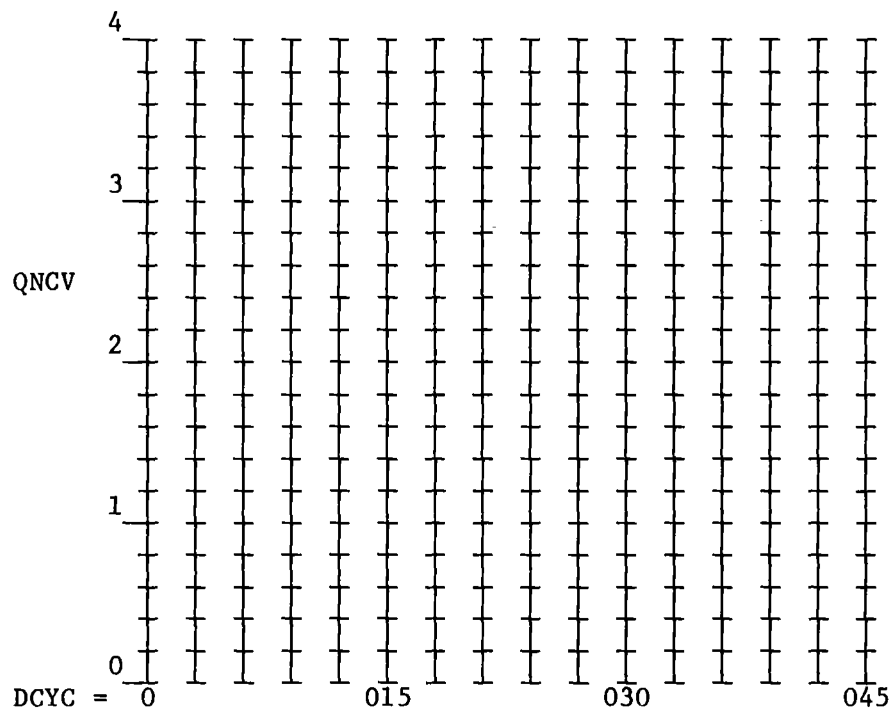
then becomes

$$QNCV = 3.516\ (1/DCYC)^{0.25}\ 1.0$$

which, in simplest form is:

$$QNCV = 3.516\ (1/DCYC)^{0.25}$$

Substituting 1, 5, 10.....45 cm for DCYC, calculate QNCV and plot the results below.



UNIT 2.2: FORCED CONVECTION

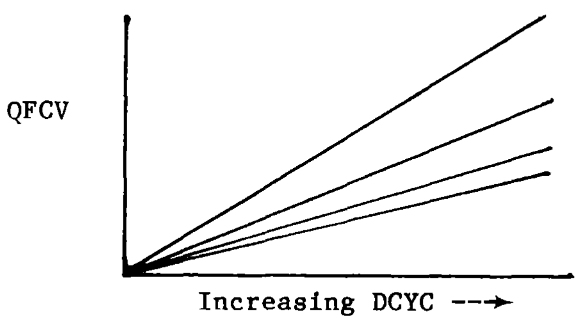
Forced convection is a form of heat loss due to movements of the air (wind) and to the movement of the animal itself. Three variables, including the wind velocity (WIVE), the diameter of the convector (DCYC), and the difference between the surface temperature of the convector and air temperature (DLTA), are used when calculating forced convection. The general formula, modified from Gates (1962), is:

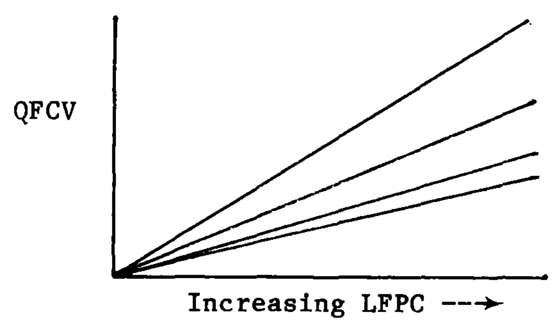
$$QFCV = 3.702\ [(WIVE^{1/3})/(DCYC^{2/3})](DLTA)(SAFC)$$

where QFCV = quantity of forced convection,
WIVE = wind velocity in cm per second,
DCYC = diameter of the cylinder in cm,
DLTA = temperature difference in °C, and
SAFC = surface area involved in forced convection, in square meters.

Formulas are also available for calculating forced convection from flat plates, where the length of the plate replaces diameter of the cylinder as the characteristic dimension.

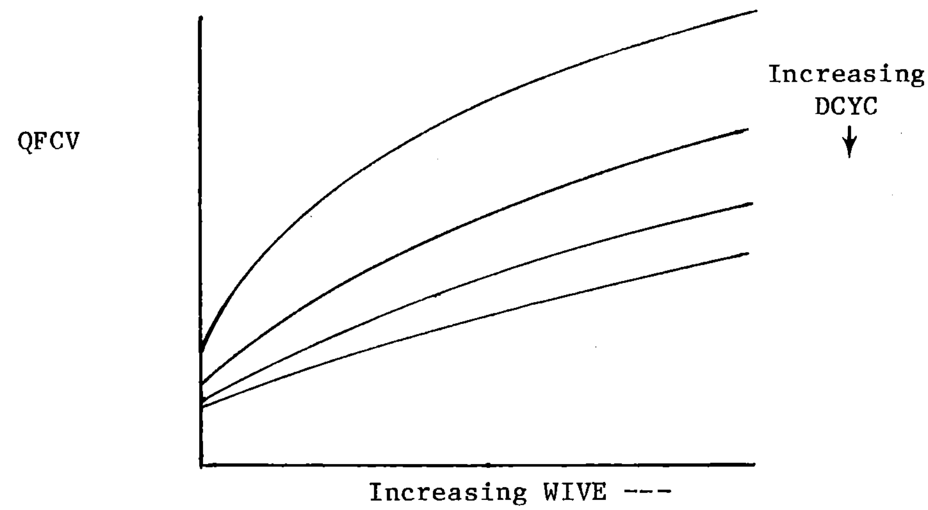
Convector geometry effects. The effects of changes in the diameter of cylinders (DCYC) and the lengths of flat plats (LFPC) are illustrated below.



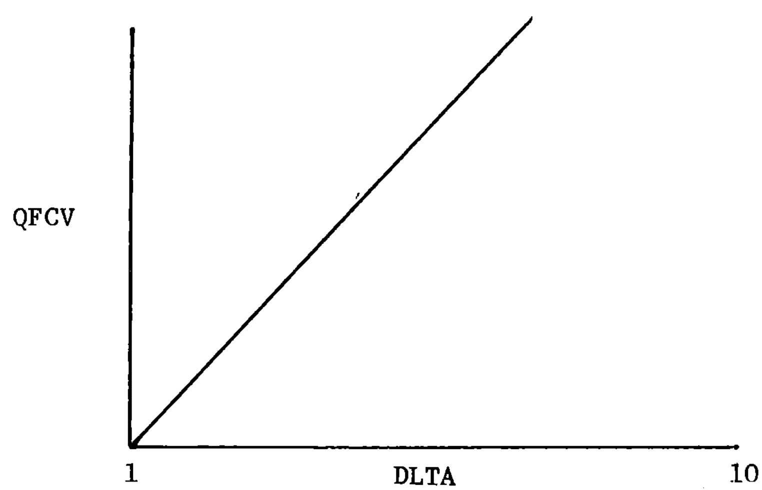


The smaller the diameter of the cylindrical convector or the length of a flat plate convector, the greater the sensitivity to changes in WIVE. Efficiency of heat loss is associated with small-diameter convectors and short plates. The non-linear characteristic of this relationship is clear.

Wind velocity effects. The results used to plot the illustrations above were based on a single wind velocity. The effects of a range of wind velocities may be plotted with a family of curves for different diameters and flat plats in relation to WIVE on the X-axis. Greater relative effects are observed at the lower wind velocities, although the absolute quantities of heat loss increase as wind velocities increase. The pattern of this relationship is illustrated at the top of the next page.

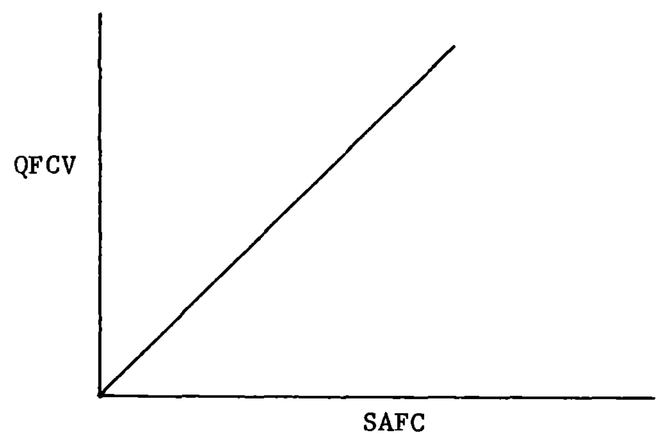


Temperature differences. When wind velocities and the characteristic dimensions of the convectors remain constant, the amount of heat loss per unit surface area is directly proportional to the temperature differences. This is obvious from the formula; DLTA functions as a simple multiplier after the non-linear effects of WIVE and DCYC or LFPC have been considered. The effects of temperature differences are illustrated below.



Calculations of these relationships are made in the WORKSHEETS that follow.

Surface areas. Heat lost by forced convection is directly proportional to wind velocities, the characteristic dimensions of the convector, and the temperature differences when these three parameters remain constant in a given set of conditions. Like DLTA discussed above, SAFC is a multiplier at the end of the formula. It is important to remember that the geometry is a very important consideration, however, since a surface area of two square meters of a very long, thin cylinder has a higher convective loss than two square meters of surface area of a short, thick cylinder.



Opportunities for calculations are given in the WORKSHEETS that follow.

LITERATURE CITED

Gates, D. M. 1962. Energy Exchange in the Biosphere. Harper and Row, Publishers, N. Y. 151 p.

REFERENCES, UNIT 2.2

FORCED CONVECTION

BOOKS

TYPE	PUBL	CITY	PAGE	ANIM	KEY WORDS-----------------	AUTHORS/EDITORS--	YEAR
aubo	gaul	loen	234	rata	the wind and the caribou	munsterhjelm,e	1953

SERIALS

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
JRMGA	27--5	401	403	odvi	radiant temps, hair surfac	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
NAWTA	35---	106	114	odvi	func aspects wind, thermal	stevens,ds; moen,	1970

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
CJZOA	38--4	679	688	rata	eff wind, moist newb htlos	lentz,cp; hart,js	1960
NJZOA	19--1	89	91	rata	surf tmps, heat los condit	wika,m; krog,j	1971
TRJOA	25-10	832	837	rata	thermal insulation of pelt	moote,i	1955
ZOLZA	53--5	747	755	rata	[body surfac heat emissio]	segal,an; ignatov	1974
JTBIA	47--2	413	420	rata	wind chill, solar radiatio	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
JANSA	35--3	624	627	doca	physic principl energ exch	morrison,sr	1972
JASIA	74--2	247	258	doca	accum, evap moist, sweatin	allen,te; bennet/	1970

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
IJBMA	20--2	139	156	doru	meteorology in anim produc	bianca,w	1976
JAPYA	37--3	443	446	doru	heat flow meters, heat los	mcginnis,sm; ingr	1974

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
JASIA	52--1	25	40	dosh	partition heat los, clippe	blaxter,kl; grah/	1959

CODEN	VO-NU	BEPA	ENPA	ANIM	KEY WORDS-----------------	AUTHORS----------	YEAR
JAPYA	20--4	796	801	mamm	hair dens, wnd spd, h loss	tregear,rt	1965
BIOJA	11-12	1030	1047	----	energy exch, cylind append	wathen,p; mitche/	1971
JTBIA	35--1	119	127	----	convect resp syst, panting	seymour,rs	1972
PRLBA	188--	395	411	----	conductin, convectn, coats	cena,k; monteith,	1975

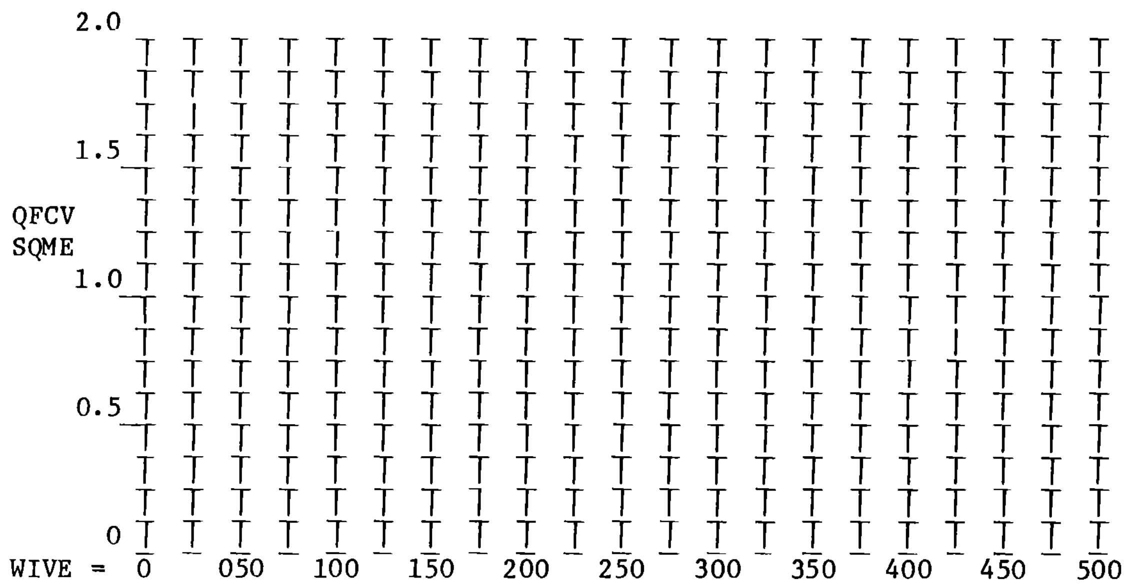
CHAPTER 15, WORKSHEET 2.2a

Forced convection in relation to wind velocity and cylinder diameter

The quantity of forced convection (QFCV) may be calculated with various combinations of wind veloctiy (WIVE) and cylinder diameter (DCYC), using the formula, given in UNIT 2.2:

$$QFCV = 3.202\ [(WIVE^{1/3})/(DCYC)^{2/3})]\ (DLTA)(SAFC)$$

Complete a series of calculations using combinations of WIVE and DCYC and the value 1.00 for DLTA and SAFC, and plot the results below.



The results, expressed as the quantity of forced convection (QFCV) per square meter (SQME) is really a convection coefficient, an expression of the efficiency of heat transfer with various combinations of wind velocity and cylinder diameter This coefficient may be multiplied by DLTA and SAFC to determine the absolute amount of heat lost by forced convection from a defined surface.