BLACK GLOBE THERMOMETER IN THE ESTIMATION OF REFLECTANCE OF FABRICS FOR TOTAL SOLAR RADIATION

by

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ABSTRACT

A rough but simple method of assessment of reflectance values of fabrics of different colours for total solar radiation including long-infrared component, has been described, which makes use of black-globe thermometer and can be conveniently used in the field. Observations taken on some fabrics of importance to the Defence Services have been reported.

Introduction

Total solar heat load on the human body depends on the reflectance of clothing for the total solar radiation, incident on the body, which consists broadly of two components. Firstly, the visible and short infra-red radiation made up of direct solar radiation, its fraction scattered by the sky, and fraction reflected by the terrain. Secondly, the secondary radiation which is exclusively long infra-red depending on the mean radiant temperature of the surrounding surfaces. While sufficient data are available on reflectance values of fabrics of different colours for direct solar radiation, similar data are lacking with respect to total solar radiation including the long infra-red component. The term "reflectance" is used here to denote the fraction of the incident radiation reflected at the clothing surface and therefore not contributing to the heat load on the body.

The Globe Thermometer

The Globe thermometer, introduced by Vernon[1] consists of a hollow 6-inch copper sphere, coated with matt blackpaint, and containing an ordinary thermometer with its bulb at the centre of the sphere. There is no provision for heating the instrument, its temperature depends solely on the environment in which it is placed. If the surfaces which surround the globe are warmer than the air, the temperature recorded by the thermometer inside the globe will be above the air temperature, and, conversely, with walls and other surroundings cooler than the air, the globe thermometer temperature will be below air temperature. The globe reaches approximate equilibrium with its surroundings in about 20 min.

The emissivity of the black globe is practically the same for visible, short and long infra-red radiation and is taken to be 0·95[2].

In an earlier paper it was shown by Majumdar and Sharma[3] that from the steady readings of the black globe thermometer in the sun, air temperature in shade and a knowledge of the reflectance value of the clothing for solar radiation, it is possible to evaluate the temperature of a thermally equivalent indoor environment with respect to the human body in the erect posture, by means of the formula,

$$Ta'—Ta = \frac{1 - F}{0 \cdot 95} (Q/Qg) (Tg—Ta) \quad .. \quad .. \quad (1)$$

where Ta is the prevailing air temperature (shade).

T_a', the air temperature corrected for solar radiation.

0·95 is the emissivity of the black globe for all radiations.

Tg is the steady reading of the black globe thermometer.

F is the reflectance value of clothing for solar radiation.

Q, the total solar radiation direct and indirect, incident on the body per unit area.

Q_g is the total solar radiation incident on the globe per unit area.

Q/Q_g is practically constant and is nearly equal to unity.[3]

Following a similar reasoning it can be shown that if two standard black globe thermometers, one of them covered with a given fabric, are simultaneously exposed to the sun then, from their steady readings in conjunction with the prevailing air temperature in shade, it is possible to work out the approximate reflectance value of the fabric for total solar radiation.

Method

Five standard black globe thermometers fitted on stands, four of them covered with closely fitting covers made of black Taffeta silk, olive green cellular, khaki cellular and white twill respectively were simultaneously exposed to the open sun for about an hour, their steady readings and the prevailing air temperature in shade were recorded. The clothed-globe reading is denoted by Tcl. The data were recorded between 1200 and 1500 hrs in the months of May and June of 1958 and March 1959. The globes were kept at about 2½ feet above the ground. The readings were mostly taken on the open kacha ground, and a few were taken on the roof of the laboratory, such that there was practically no obstruction from the sides.

Results

The observations have been graphically represented in Fig. 1, in which $T_{cl}—T_a$ has been plotted against $Tg—Ta$, separately for each fabric.

Table 1 (see appendix) summarizes the observations taken on these globes and the air temperature in shade.

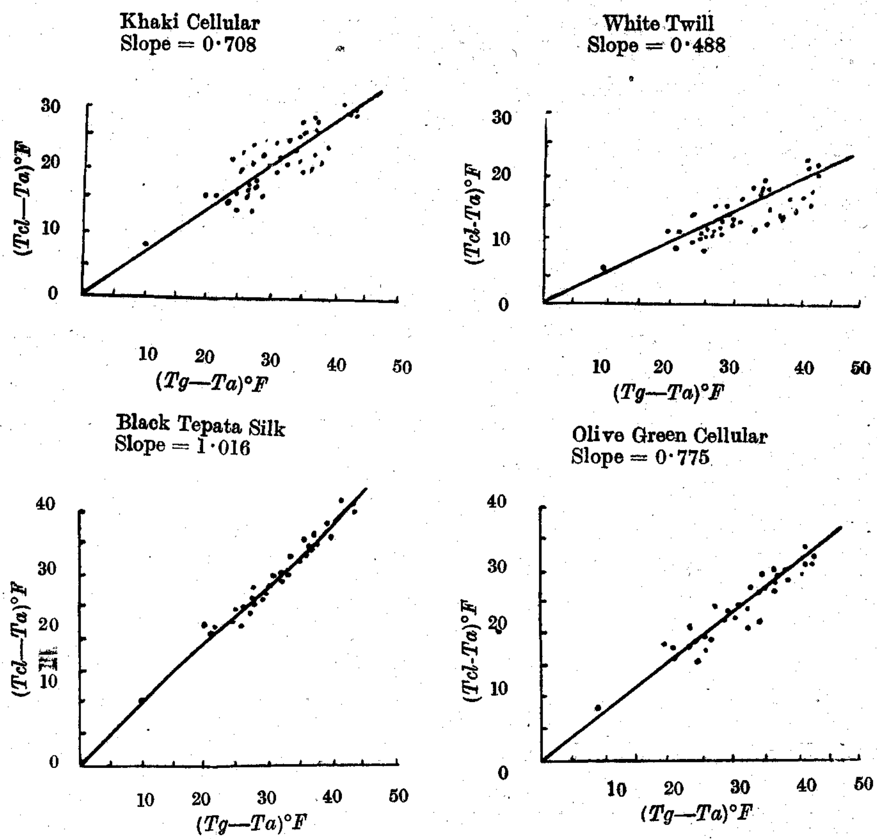

FIG 1—Relationship between clothed-globe reading (Tcl) and Black-Globe reading (Tg), [both expressed as total-solar-radiation increments to dry-bulb temperature (Ta)], for four colours of fabric.

Statistical analysis of the data

The values of the correlation coefficients based on forty six observations are as follows:—

$r_{AB} = 0{\cdot}9834$

$r_{AC} = 0{\cdot}8533$

$r_{AD} = 0{\cdot}8092$

$r_{AE} = 0{\cdot}8177$

Where $A = Tg - Ta$

$B = Tcl$ (black)$-Ta$

$C = Tcl$ (Olive green)$-Ta$

$D = Tcl$ (Khaki)$-Ta$

$E = Tcl$ (White)$-Ta$

All the four values are highly significant.

The regression lines of B,C,D, and E on A passing through the origin were drawn and the corresponding regression coefficients were found out to be 1·016, 0·7745, 0·7084 and 0·4884 respectively. Multiplying these values by 0·95 we got 1-F as 0·96, 0·74, 0·67 and 0·46. Substracting these values from 1 we got the reflectance values for total solar radiation with black Taffeta silk, olive green cellular, khaki cellular and white twill as 0·04, 0·26, 0·33 and 0·54.

Conclusion

The black globe thermometer employed in the manner described in this paper appears to be a reasonably simple and reliable field instrument for rough assessment of reflectance values of fabrics for total solar radiation including the secondary long-infra-red component.

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References

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3. Majumdar, N.C. and Sharma, R.N., *Def. Sci. J.*, **10**, 51, 1960.

Appendix

TABLE I

Observations on covered and uncovered black globe.

Mean Dry bulb	Mean black Globe		Clothed Globe Tcl°F							
			Black		Olive green		Khaki		White	
Ta°F	Tg°F	Tg—Ta°F	Tcl	Tcl—Ta	Tcl	Tcl —Ta	Tcl	Tcl—Ta	Tcl.	Tcl—Ta
107·0	134·2	27·2	134·0	27·0	127·6	20·6	125·5	18·5	119·3	12·3
107·0	132·1	25·1	132·5	25·5	126·7	19·7	124·8	17·8	118·8	11·8
105·8	133·5	27·7	133·2	27·4	127·0	21·2	124·5	18·7	119·0	13·2
104·0	136·0	32·0	135·0	31·0	128·0	24·0	125·8	21·8	119·5	15·5
104·0	137·8	33·8	137·8	33·8	130·6	26·6	128·6	24·6	121·7	17·7
105·2	137·3	32·1	136·5	31·3	129·1	23·9	127·0	21·8	120·7	15·5
103·7	136·0	32·3	138·0	34·3	130·8	27·1	129·0	25·3	122·0	18·3
108·5	134·5	26·0	133·2	24·7	126·3	17.8	124·8	16·3	120·0	11·5
108·1	132·5	24·4	133·5	25·4	127·3	19·2	125·0	16·9	120·0	11·9
109·3	135·5	26·2	135·5	26·2	128·7	19·4	126·5	17·2	120·8	11·5
108·0	132·2	24·2	133·1	25·1	126·8	18·8	124·8	16·8	119·3	11·3
106·2	130·8	24·6	128·5	22·3	122·0	15·8	120·0	12·8	115·0	8·8
106·5	127·0	20·5	127·5	21·0	122·0	15·5	121·0	14·5	115·5	9·0
106·8	130·0	23·2	130·0	23·2	124·3	17·5	122·0	15·2	117·2	10·2

TABLE 1—*contd.*

Observations on covered and uncovered black globe

Mean Dry bulb	Mean black Globe		Clothed Globe Tcl° F							
			Black		Olive green		Khaki		white	
Ta °F	Tg °F	Tg—Ta °F	Tcl	Tcl—Ta	Tcl	Tcl—Ta	Tcl	Tcl—Ta	Tcl	Tcl—Ta
106·2	135·0	28·8	135·5	29·3	129·0	22·8	126·5	20·3	120·2	14·0
107·5	132·4	24·9	132·0	24·5	126·4	18·9	125·0	17·5	119·0	11·5
103·0	133·8	30·8	134·5	31·5	127·8	24·8	126·0	23·0	119·8	16·8
101·8	111·3	9·5	112·5	10·7	110·5	8·7	110·0	8·2	106·8	5·0
103·5	124·5	21·0	126·0	22·5	121·2	17·7	120·0	16·5	115·0	11·5
104·9	124·3	19·4	127·5	22·6	123·0	18·1	122·0	17·1	116·5	11·6
106·5	135·5	29·0	135·5	29·0	128·9	22·4	122·7	16·2	121·0	14·5
108·0	133·5	25·5	132·2	24·2	126·0	18·0	120·5	12·5	120·0	12·0
106·8	149·0	42·2	147·8	41·0	138·2	31·4	136·5	29·7	127·7	20·9
105·8	146·9	41·1	147·7	41·9	137·2	31·4	135·4	29·6	127·5	21·7
106·9	149·4	42·5	149·5	42·6	139·1	32·2	137·5	30·6	129·0	22·1
105·5	146·1	40·6	149·0	43·5	139·2	33·7	137·2	31·7	128·5	23·0
106·5	144·5	38·0	145·8	39·3	136·5	30·0	135·0	28·5	126·5	20·0
105·0	139·3	34·3	140·0	35·0	132·6	27·6	131·3	26·3	123·3	18·3
105·0	141·0	36·0	143·0	38·0	135·2	30·2	134·0	29·0	125·0	20·0

105·6	140·1	34·5	143·0	37·4	135·1	29·5	134·0	28·4	125·2	19·6
95·0	129·6	34·6	130·7	35·7	122·3	27·3	121·5	26·5	113·0	18·0
95·8	131·9	36·1	132·4	36·6	124·1	28·3	123·0	27·2	114·8	19·0
95·3	131·6	36·3	132·0	36·7	124·4	29·1	123·7	28·4	114·2	18·9
95·0	118·2	23·2	120·5	25·5	116·8	21·8	117·0	22·0	109·0	14·0
95·0	123·5	28·5	123·5	28·5	118·5	23·5	118·0	23·0	110·3	15·3
94·9	121·6	26·7	124·1	29·2	119·8	24·9	119·5	24·6	110·8	15·9
84·5	112·5	28·0	112·2	27·7	104·5	20·0	102·0	17·5	95·8	11·3
84·1	110·2	26·1	111·5	27·4	104·5	20·4	102·1	18·0	95·5	11·4
79·4	112·1	32·7	111·1	31·7	99·8	20·4	97·2	16·8	90·8	11·4
80·1	114·5	34·4	115·0	34·9	103·0	22·9	100·1	20·0	93·0	12·9
80·4	110·0	29·6	111·5	31·1	103·2	22·8	101·8	21·4	93·4	13·0
83·6	120·0	36·4	119·8	36·2	110·4	26·8	107·0	23·4	99·5	15·9
84·5	123·2	38·7	122·0	37·5	112·8	28·3	109·2	24·7	101·0	16·5
79·3	107·0	27·7	107·2	27·9	99·5	20·2	97·0	17·7	91·1	11·8
79·7	110·0	30·3	110·1	30·4	102·0	22·3	99·8	20·1	92·8	13·1
79·9	109·0	29·1	109·0	29·1	102·0	22·1	99·0	19·1	92·5	12·6