Thermal Effects of Clothing in Saharan Regions

[1]Olusegun H.D, [2]Adekunle A.S, [3]Ohijeagbon I.O, [4]Orhevba B.

Abstract:

The preferred dark coloured apparel worn by the Tuaregs of North Africa and the other desert dwellers of Northern Nigeria instigated this study. Experimenters discover that when dressed in dark apparels, they were more comfortable than when they put on white apparels. The solar radiant energy for the precinct where tests were done was 857.3Wm^{-2}, of which ~ 84% was diffused by dark apparel. White apparel diffused ~ 57% of solar radiation. The total human body heat energy produced was 512.9Wm^{-2}. The dark apparel discharged 378Wm^{-2} to the surrounding, whereas white apparels discharged 145Wm^{-2} to the surroundings. The "private climate" domain under the human skin did appear to work better when shielded by a dark cloth rather than a white one, so that there was an overall comfort experienced when dressed in dark apparel in hot environment.

Key words: radiation, apparel, discharge, capillary bed, "private climate", domain.

Introduction

The task of clothing is besides fashionable embodiment and expression, but includes the protection against harmful environmental stresses and climatic conditions. On this account, the well being, and productivity of humans, largely depends on clothing. Clothing also acts as a resistance to heat and moisture transfer between skin and environment. In this way it can protect against extreme heat and cold, but at the same time it hampers the loss of superfluous heat during physical effort "[1], [2]". Heat and moisture transport through clothing, involve complex processes and are coupled through evaporation, condensation, sorption and desorption of moisture "[3], [4]". Performing work in a warm or hot environment is in general more stressful for the worker than performing similar work in a cold environment. The physical load, which accompanies heat exposure, can increase the risk of danger to the worker's safety and health. The need to wear (protective) clothing in such conditions may lead to intolerable heat strain, as the clothing will have a detrimental effect on the workers ability to lose heat to the environment..

The capacity of the body to retain heat or to lose heat to the environment is strongly dependent on a number of external parameters such as: air temperature, radiant temperature, surface temperature, air humidity and wind speed [5]. Information gathered about the Tuaregs who lived in the desert, the dwellers in the hot regions of the far northern borders of Nigeria and all the nomads of the Saharan areas showed that they preferred dark, black coloured cotton robes for their clothing [6]. Normally the body temperature is about 37 °C. This value is achieved by balancing the amount of heat produced in the body with the amount lost. Heat production is determined by metabolic activity. When at rest, this is the amount needed for the body's basic functions, of respiration and heart function to provide body cells with oxygen and nutrients. When working however, the need of the active muscles for oxygen and nutrients increases, and the metabolic activity increases [7]. When the muscles burn these nutrients for mechanical activity, part of the energy they contain is liberated outside the body as external work, but most of it is released in the muscle as heat. The ratio between this external work and the energy consumed determines the efficiency with which the body performs the work. For heat loss from the body, several pathways are available. A minor role is taken by conduction. Only for people working in water, in special gas mixtures (prolonged deep-sea dives), handling cold products or in supine positions, does conductivity become a relevant factor. More important for heat loss is convection. When air flows along the skin, it is usually cooler than the skin. Heat will therefore be transferred from the skin to the air around it. Also heat transfer through electro-magnetic radiation can be substantial. When there is a difference between the body's surface temperature and the temperature of the surfaces in the environment, heat will be exchanged by radiation. Finally, the body possesses another avenue for heat loss, which is heat loss by evaporation. Due to the body's ability to sweat, moisture appearing on the skin can evaporate, with which large amounts of heat are dissipated from the body. By warming and moisturising the inspired air, the body loses an amount of heat with the expired air, which can be up to 10% of the total heat production [8].

For body temperature to be stable, heat losses need to balance heat production. If they do not, the body heat content will change, causing body temperature to rise or fall [9]. In combination with the thermal interaction of the human body, Shitzer et al 1985 [10] observed the heat exchange with clothing, even considering fluid cooled garments. Fiala et al 1999 [11] and Xu et al 1997 [12] developed their own human thermoregulation models, including heat and moisture transfer through clothing and accumulation effects. With a sweating thermal manikin, Celcar et al 2008 [13] investigated the characteristics of clothing. In order to determine thermal comfort it is necessary to understand the thermal behaviour of the clothing [8]

There is a domain of the skin, ~3mm deep, called "private climate", where temperature changes from interior skin temperature to exterior surrounding air temperature [6]. It was discovered that the transfer of solar radiant heat through the "private climate" and through the skin to the human body, is dependent on the type and colour of clothing worn and the colour of the skin, that is, whether Black or Caucasian. The blood circulation within the human body is transferred through a surface area of capillary bed of 160m^2, which moves the heat by convection. The velocity of the human blood is less than 2mms^{-1}. The Caucasian is known to absorb more radiation from the sun, an emissivity of 0.84, than the Negroid, 0.57. Hence Negroid can withstand solar radiation while Caucasian is prone to sun burn.

This paper focuses on the thermal characteristics of black clothing, dealing with heat and mass transfer from the skin through the clothing to the environment in the Saharan regions, in an effort to investigate the long practised custom of preferred black robes worn by the Tuaregs, that is contrary to the accepted white robes which are scientifically believed to reduce heat by reflection.

Theoretical Calculations:

When excessive body heat is removed from inside the human body, it brings relief and comfort. The four ways human body heat (hbh) can be dissipated and removed from inside the body to the environment are, by perspiration and evaporation q_{sw}, conduction q_{cd}, convection q_{cv} and by radiation q_{br}.

Human body heat discharged through perspiration and evaporation:

The human body will perspire when subject to the daily activity of work, and exercise. At other times, humans will perspire when the surrounding temperature is hotter than that of the human body. The heat removed by perspiration and evaporation through sweat is the product of the latent heat of vaporisation of sweat L_{sw} and volume of water per hour from sweat v_w.

That is, $q_{sw} = L_{sw} = 2.46x4 = 9.84kJh^{-1}$ (1)

$$= \frac{9.84x1000}{60x60} = 2.73W$$

Less 60% loss to evaporation on flat ground.

Hence, $q_{sw} = 0.4x2.73 = 1.09W$

Human body heat discharged by conduction q_{cd} :

The hbd discharged by conduction q_{cd}, is inversely proportional to the distance (y), the hbh will move from the interior to the exterior of the human body. It is directly proportional to the temperature difference (t) between the interior and exterior of the human body, and the area (A) of the skin. The equation for the transfer of heat for conduction is,

$$q_{cd} = A\frac{\delta t}{\delta x} = kA\frac{\delta t}{\delta x} \quad (2)$$

where k is the conductivity coefficient (Wmk^{-1})

The heat transfer here goes from the centre of the body to the skin q_{bs}, then to the space between skin and robe q_{so}. The assumptions are that the thickness of skin is 10mm over 1m^2 of skin, [14].

Therefore, $q_{cd} = q_{bs} + q_{so}$

The heat discharged from body to the skin is,

$$q_{bs} = k_b A_b \frac{\delta t_b}{\delta x t_b} = \frac{18\times1\times(37-32)}{10} = 9kcalh^{-1},$$

where k_b, A_b ,t_b are body conductivity coefficient, body surface area, and body temperature respectively. About 3mm deep into the skin, there is a domain where the skin temperature changes to atmospheric. The domain occurs naturally, creating an energy balance with the environment. The area is referred to as the "private climate".

Hence, $k_{sk} x A_s x \frac{\delta t_s}{\delta x_s} = 291W$ (3)

Human body heat discharged by convection q_{cv}

This is the sum of the hbh discharged by skin convection q_{sc} and blood convection q_{bc} .

i.e , $q_{cv} = q_{sc} + q_{bc}$ and $\frac{\delta q_{sc}}{\delta t} \alpha A \delta t$

or $q_{cv} = hA_s(t_s - t_a)$ (4)

where t_s , t_a , are skin and ambient temperatures respectively, with h being the heat transfer coefficient due to "private climate" between skin and environment. The value of h is given as $h = 14.5v^{0.5} = 6.95Wm^{-3}k^{-1}$, where

v =0.23ms^{-1} (Nave 2002)

$q_{cv} = 27.80W$

$q_{bc} = h_{cb}A_{cb}(t_b - t_s)$ (5)

where h_{cb}, A_{cb}, t_b are heat transfer coefficient of capillary bed, area of capillary bed, and the body temperature respectively. The blood circulation moves the hbh to the skin from the body interior. The velocity of the human blood is 2mms^{-1} and $h_{cb} = 0.205Wm^{-2}k^{-1}$ which when substituted in (5) gives, $q_{bc} = 164W$

Therefore, $q_{cv} = 27.8 + 164 = 191.8W$

Human body heat discharged by radiation q_{br}

The emission of radiant energy from the human body is known to be proportional to the area of the transmitting body and to temperature to the 4th power. For a real body the proportional constant is $\epsilon\sigma$, so that $q_{br} = \epsilon\sigma A_{br} T_{br}^4$ (6)

Where, A_{br} and T_{br} are human body area and temperature , σ is the Stefan-Boltzmann constant ($Wm^{-1}K^{-4}$), ϵ is the emissivity of human skin. When a weighted average of 0.838 for Black people skin and $5.67x10^{-8}Wm^{-1}K^{-4}$ for a Caucasian person are used along with equation (7), which is,

$$q_{br} \alpha A_{br} T_{br}^{4-} T_s^4 \quad (7)$$

where T_s is the temperature of the surrounding, the hbh discharged by radiation q_{br}=28.5W is obtained.

When an aggregate of the **total human body heat** is taken, then,

$$q_T = q_{sw} + q_{cd} + q_{cv} + q_{br} = 512.4W$$

Material size for black and white robes:

The size of material for an average man for a robe, "agbada" and trouser is 10.452m^2 or 10yards. The material requirement varies in size depending on how large or tall the wearer, male or female, is.

Experimental procedures:

Two males of approximate weight and height were used for the experiment, one wearing black robe the other wearing white. They were both Negros. The robes or apparels were worn allowing a space of about 10cm between the skin and robe by the use of wooden props. Thermometers were attached to the props which measured the temperatures of the human body, the space between body and robe, the robe and the atmosphere. The experimenters were for most of the time under the sun in an open environment. Temperature records were taken from which energy calculations were carried out by the use of a computer.

Results and discussion:

The maximum solar energy recorded for the Ilorin precinct at the hottest time of the day between 1pm and 2.30pm, was 857.3Wm^{-2} for mid September. The total hbh discharged by an average adult man was estimated as 512.4Wm^{-2}. Figure 1 showed that the human body temperature remained normal and was about the same when black robe or white robe was worn indoors. However, changes occurred as the experimenters stepped outdoors into the sun and Figure 2 showed the black robe temperature as having risen above that of the white robe by 3^{0}C at 10:30am. At the hottest recorded periods of 12.30 and 2.15pm, the black robe and the white robe wearers recorded temperatures of 35^{0}C and 33^{0}C respectively. Figure 3 showed the difference of 1^0 to 3^{0}C for all other readings. When the net body energy between the wearers of black and white apparels was compared, Figure 4, the noticeable differences were 40Wm^{-2} between the period of 9.45 to 11.30am, 60Wm^{-2} at 11.45am, 90Wm^{-2} between the period of 12.15 and 12.45pm, 50Wm^{-2} was recorded at 3.45pm, and 60Wm^{-2} at 6.15pm.

The curves on Figure 4 clearly showed that the energy reduction when black robe was worn, exceeded that when white robe was used.

White bodies are known to reflect light and heat, but an unusual phenomenon occurred when experimenters discovered that wearing black robes actually made then more comfortable than when they wore white robes. It was also observed that ~43% of the radiant heat of the sum was allowed into the human body by white robe. In comparison, the black robe only allowed ~16% of the solar radiation into the human body.

It appeared there is a "private climate" domain that is 3mm in the skin which has a natural capacity to protect the human skin from solar radiation. It was especially effective when the external apparel worm was black. The "private climate" domain was also active in the discharge of internally generated heat due to evaporation, perspiration, conduction, convection, and radiation. It allowed more heat energy to be taken away from the body of a black robe wearer, 378Wm^{-2}, than from the body of a white robe wearer, 145Wm^{-2}. It was possible that along with its inbuilt capacity to reduce solar radiation and to extract heat energy from the human body especially of wearers of black apparel, the "private climate" domain had the ability to increase or decrease in thickness depending on the intensity of heat it had to dispense.

ISSN 2229-5518

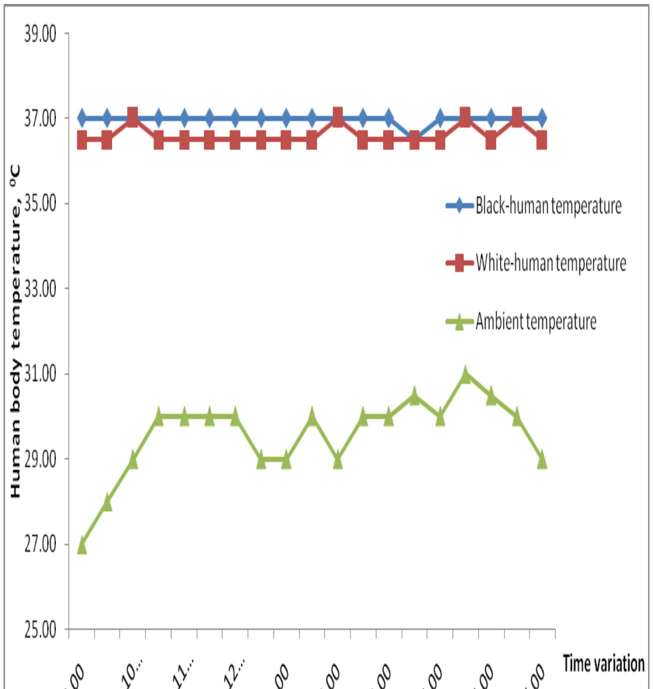

Figure 1: Human body temperature changes with time

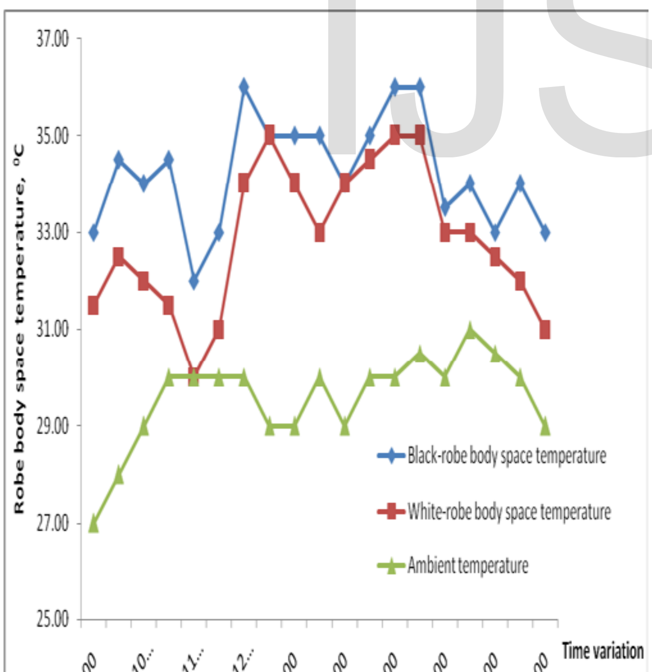

Figure 2: Robe body space temperature changes with time

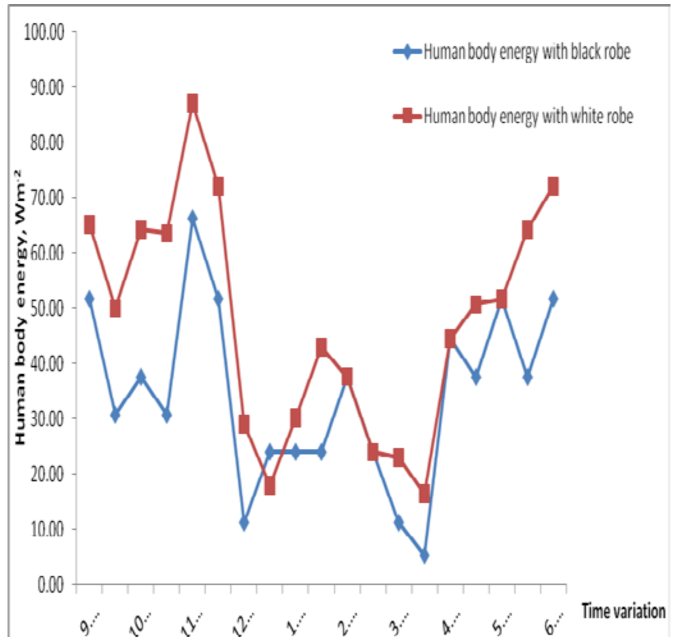

Figure 3: Human body energy changes with time

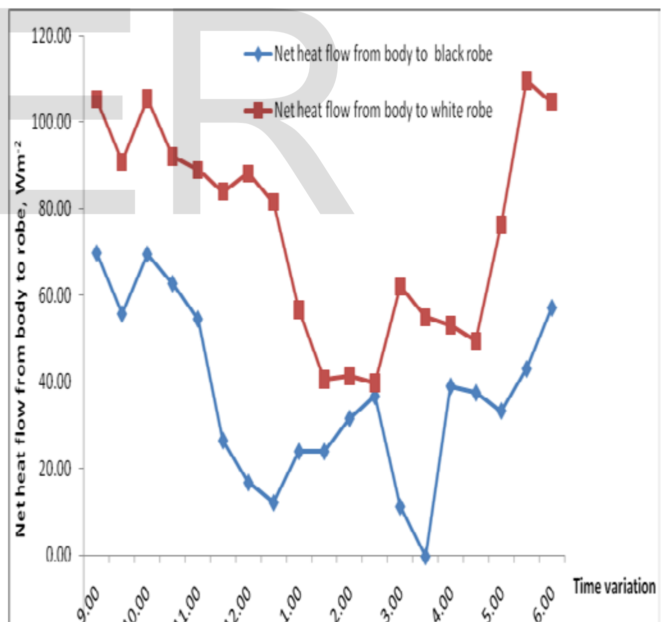

Figure 4: Changes in net heat flow with time from body to robe

Conclusion:

It was observed that the Tuareg people and other desert inhabitants of the Saharan Regions were right to have chosen to wear black apparels instead of the scientifically recognized white ones. Investigation showed that in this location where solar radiation was 857.3Wm^{-2} and with an internal body heat of 512.9Wm^{-2} generated by the experimenters, the black apparel allowed ~16% of radiant energy to the body. The white apparel allowed ~43% of radiant energy. The black apparel also discharged $\sim 73\%$ of internal body heat to the surroundings, while the white apparel discharged only $\sim 28\%$. Consequently, the black apparel was more comfortable to wear in hot weather conditions than white apparel. It was possible that the presence of a "private climate" domain $\sim 3mm$ deep in the human skin, which had the inbuilt capacity to reduce solar energy and to extract heat energy from the human body, favoured the experimenter dressed in black apparel and was responsible for his comfort.

Refrences

1. Havenith, G. 1999. Heat balance when wearing protective clothing. Annals of Occupational Hygiene Society. Vol. 43, No. 5., pp 289 – 296
2. Aaron, M., Nancy, L. C. 2002. Saharan Africa: Potential production source for textiles and apparel. Journal of Textile and Apparel, Technology and Management. Vol. 2, No. 3
3. Mark, G. M., Harriet, M., Peter, B., Victor, C., Emiel, D. H., Inguar, H., Wolfgang, N., George, H. 2008. Dry and wet heat transfer through clothing dependent on the clothing properties under cold conditions. International Journal of Occupational Safety and Ergonomics. Vol. 14, No. 1., pp 69 – 76
4. Li, Y., Zhu, Q. Y. 2003. A model of coupled liquid moisture and heat transfer in porous textiles with consideration of gravity. Numerical Heat Transfer Part A, Applications. Vol.43, No.5, pp 501 – 523
5. Wu, H., Fan, J. 2008. Study of heat and moisture transfer within multi-layer clothing assemblies consisting of different types of battings. International Journal of Thermal Sciences. Vol. 47., No. 5., pp 641 – 647
6. Olusegun, H. D. 2008. Investigation into effects of clothing in Saharan regions. Journal of the Energy Institute. Vol. 19., No. 38.
7. Lawson, L. K., Crown, E. M., Ackerman, M. Y., Dale, J. D. 2004. Moisture effects in heat transfer through clothing systems for wildland fighters. International Journal of Occupational Safety and Ergonomics. Vol. 10, No.3 pp 227 – 238
8. Voelker, C., Hoffmann, S., Kornadt, O., Arens, E., Zhang, H., Haizenga, C. 2009. Heat and moisture transfer through clothing. Eleventh International IBPSA Conference. 27th – 30th July, Glasgow, Scotland.
9. Voelker, C., Kornadt, O. 2009a. Assessing thermal comfort using CFD along with a numerical thermal manikin. Proceedings of 4th IBPC, 15th – 18th June 2009, Istanbul, Turkey.
10. Shitzer, A., Chato, J. C. 1985. Thermal interaction with garments. In A. Shitzer and R. C. Eberhart (ed), Heat Transfer in Medicine and Biology. Analysis and Applications. Vol. 1. Pp375 – 388 Plenum press.
11. Fiala, D., Lomas, K. J., Stohrer, M. 1999. A computer model of human thermoregulation for a wide range of environmental conditions: the passive system. Journal of Applied Physiology. Vol. 87, No. 5., pp 1957 – 72
12. Xu, X., Werner, J. 1997. A dynamic model of the human/clothing/environment system. Applied Human Science. Vol. 16., No. 2, pp 61- 75.
13. Celcar, D., Meinander, H., Gersak, J. 2008. Heat and moisture transmission properties of clothing system evaluated by using a sweating thermal manikin under different environmental conditions. International Journal of Clothing Science and Technology. Vol. 20, No. 4, pp 240 – 252
14 Nave R. 2002. Modelling the cooling of the human body 6-9 Hyper-Physics .

Prof. H. D. Olusegun is currently a professor of Mechanical Engineering at the Department of Mechanical Engineering, Federal University of Technology, Minna, Niger State, Nigeria. His research interests are design and production of medium and small scale machines, thermal energy and hydro turbine energy. E-mail: olusegunhenry@yahoo.com

Dr. A. S. Adekunle is a lecturer in the department of mechanical engineering, University of Ilorin, Ilorin, Nigeria. He researches in the area of production, design and materials.
E-mail: adekunlebayo@yahoo.com

Dr. I. O. Ohijeagbon is a lecturer in the department of mechanical engineering, University of Ilorin, Ilorin, Nigeria. His research interest is in the area of thermal energy, materials and design.
E-mail: idehaiohi@yahoo.com

Engr. B. A. Orhevba is a lecturer at the Department of Agricultural and Bio-Resources Engineering, _Federal University of Technology, Minna, Niger State, Nigeria. Her research areas are postharvest technology, food engineering, and renewable energy, Email: borhevba@yahoo.com